



***UNDERGRADUATE STUDENT
ACCEPTANCE OF HAPTIC
SIMULATION IN GROSS
ANATOMY LEARNING***

by

Soonja Yeom

MComp, GrdDipAppComp, BA

Submitted in fulfilment of the
requirement for the Degree of
Doctor of Philosophy

University of Tasmania

March 2016

Unless the LORD builds the house,
the builders labour in vain.
Unless the LORD watches over the city,
the guards stand watch in vain.

Declaration

I certify that this thesis contains no material that has been accepted for the award of any other degree or diploma in any institute, college or university. In addition, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text of the dissertation.

Soonja Yeom

Rights

This work is licensed under the Creative Commons Attribution 3.0 Unported License. To view a copy of this license, visit

<http://creativecommons.org/licenses/by/3.0/> or send a letter to Creative

Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA.

The work is provided to the University Library for open access dissemination.

Soonja Yeom asserts the moral right to be recognised as the author of this thesis.

Soonja Yeom certifies that the thesis contains no material subject to third-party copyright, that the owner of the copyright has not approved to be incorporated in the thesis.

Soonja Yeom

Acknowledgement

I would like to express my gratitude to all those who helped me in this PhD candidature. Professor Tom Furness inspired and encouraged me to pursue this journey. Professor Mark Billingham as the Director of HITLab NZ provided his feedback on my thesis topic as well as providing the 3D organ models.

This project was started with the support of the University of Tasmania through a teaching development grant.

I would especially like to thank my supervisors Dr Andrew Fluck, Dr Derek Choi-Lundberg and Professor Arthur Sale for all their advice, ideas and support. I cannot thank all of them enough, especially Dr Choi-Lundberg. They are the best!

Thanks to all the University staff and students who took part in the study for without their cooperation and enthusiasm this research would not have been possible. Thanks to Jaey Kim for his willingness to spend his time assisting during the implementation stage as well as the user testing sessions.

Dr Leonie Ellis and Mrs Nicole Herbert were great for their understanding and patience. Also thanks to David Herbert for his technical assistance. I would also

like to thank my family for the continual support and encouragement they offered throughout the candidature.

There are numerous people who have supported in a way or another, far and near.

Although I do not write all the names here in the book, I write them in my heart.

Most of all, I thank Him for His patience and encouragement to my slow growth.

Statement of Co-Authorship

The publications of the work undertaken in the course of this research are the following:

Yeom S. 'Augmented Reality for Learning Anatomy' In G. Williams, N. Brown, & B. Cleland (Eds.), *Changing Demands, Changing Directions. Proceedings ascilite Hobart 2011*

Yeom S, Fluck A, Sale A, Choi-Lundberg D, 'Exploring augmented reality for sustainable delivery of anatomy teaching and learning', *Teaching Matters 2012 - Conference Handbook*, 4th December 2012, Launceston, Tasmania, pp. 39. (2012)

- Ms Soonja Yeom (85%) is the primary author,
- Dr Andrew Fluck (5%) of Faculty of Education,
- Professor Arthur Sale (5%) of School of ICT and Engineering,
- Dr Derek Choi-Lundberg (5%) of School of Medicine of the University of Tasmania, provided general guidance and editing advice as supervisors.

Yeom S, Choi-Lundberg D, Fluck A, Sale A, 'User Acceptance of a Haptic Interface for Learning Anatomy', *Proceedings of the IADIS International Conference E-Learning 2013*, 22-26 July 2013, Prague, Czech Republic, pp. 239-246. ISBN 978-972-8939-88-5 (2013)

- Ms Soonja Yeom (65%) is the primary author,
- Dr Andrew Fluck (10%) of Faculty of Education,
- Professor Arthur Sale (5%) of School of ICT and Engineering,
- Dr Derek Choi-Lundberg (20%) of School of Medicine of the University of Tasmania, provided general guidance and editing advice as supervisors.

Yeom S, Choi-Lundberg DL, Fluck AE, Sale A, 2017. 'Factors influencing undergraduate students' acceptance of a haptic interface for learning gross anatomy' *Interactive Technology and Smart Education* 14(1): 50-66. DOI: 10.1108/ITSE-02-2016-0006

- Ms Soonja Yeom (60%) is the primary author,
- Dr Andrew Fluck (5%) of Faculty of Education,
- Professor Arthur Sale (5%) of School of ICT and Engineering,
- Dr Derek Choi-Lundberg (30%) of School of Medicine of the University of Tasmania, provided general guidance and editing advice as supervisors.

*We the undersigned agree with the above stated proportion of work undertaken
for each of the above published manuscripts contributing to this thesis.*

Signed:

Date: 20/2/2016

Professor Arthur Sale
Supervisor
School of Engineering and ICT
University of Tasmania

Signed:

Date: 20/2/2016

Dr. Andrew Fluck
Supervisor
Faculty of Education
University of Tasmania

Signed:

Date: 20/2/2016

Dr. Derek Choi-Lundberg
Supervisor
School of Medicine
University of Tasmania

Abstract

Factors influencing undergraduate students' acceptance of a computer-aided learning (CAL) resource for learning anatomy were researched and evaluated. The resource used the Phantom Omni haptic stylus, which enables the user to rotate, receive touch and kinaesthetic feedback, and display the names of three-dimensional (3D) human anatomical structures. The perceived value of the system was investigated with respect to user characteristics and system functionality.

The Learning Anatomy with Haptic Feedback System (LAHFS) was developed using the software development life cycle over three stages. It was tested by students enrolled in bachelor degrees, including medicine, health sciences, education, and computing. Their responses and attitudes towards LAHFS were investigated using action research and design research methodology frameworks, and quantitative and qualitative data were analysed using mixed methods.

Participants generally thought the haptic learning system was useful, was easy to use, and that they had performed well with it. Their perception of any negative aspects was low, with little experience of mental or physical stress.

User intention to use the system or recommend it to others correlated with their perception of usefulness and ease of use, more strongly with the former. Ease of use ratings were significantly correlated with perceptions of system usefulness and the usefulness of a quiz introduced in the final version. Students with greater kinaesthetic learning preferences tended to rate the system higher, and students with prior experience with 3D interfaces had higher intention to use the system. Previous experience with haptic interfaces did not affect user acceptance. Despite rating their performance with the system lower, females were more likely to use or recommend the system than males.

Qualitative analysis of feedback on the LAHFS system indicated that haptic feedback and 3D visualisation were considered the best aspects of the system. Suggested improvements included more rapid response times and extension to a three dimensional display. Rankings of various learning resources suggested LAHFS may be a better way of learning anatomy than websites, other software, or anatomical atlases. Ease of use ratings declined across the three versions as modules were added and system complexity increased.

Much previous research relating to haptic devices in medical and health sciences has focused on advanced trainees learning surgical or procedural skills. This study suggests that incorporating haptic feedback into virtual anatomical models is a useful strategy at an undergraduate level.

Table of Contents

1	CHAPTER 1 INTRODUCTION	16
1.1	THESIS CLAIM	16
1.2	PURPOSE OF THE STUDY	17
1.3	DEFINITION OF TERMS.....	17
1.4	RESEARCH FOCUS	19
1.5	STRUCTURE OF THE THESIS	19
2	CHAPTER 2 LITERATURE REVIEW	21
2.1	INTRODUCTION.....	21
2.2	TECHNOLOGY IN LEARNING - COMPUTER AIDED LEARNING.....	22
2.2.1	<i>Brief History of Technology in Learning</i>	<i>22</i>
2.2.2	<i>Multimedia in learning</i>	<i>26</i>
2.2.3	<i>Haptic Technology in Learning.....</i>	<i>31</i>
2.3	EDUCATIONAL THEORY ABOUT TECHNOLOGY	34
2.3.1	<i>Educational Theories</i>	<i>34</i>
2.3.2	<i>Technology Acceptance Model</i>	<i>35</i>
2.4	RESOURCES IN LEARNING ANATOMY	36
2.5	HAPTIC TECHNOLOGY IN MEDICAL AREAS.....	40
2.5.1	<i>Anticipated benefits of haptic feedback in learning anatomy.....</i>	<i>42</i>
2.5.2	<i>Interactive Interface</i>	<i>44</i>
2.6	HAPTIC DEVICES, AND THE PHANTOM OMNI AS AN EXAMPLE	45
2.7	OTHER FACTORS AFFECTING LEARNING AND USER ACCEPTANCE – LEARNING STYLES AND GENDER	
	47	

2.7.1	<i>Learning Styles.....</i>	47
2.7.2	<i>The VARK tool</i>	48
2.7.3	<i>Gender difference in User Acceptance.....</i>	49
2.8	RESEARCH QUESTIONS.....	50
3	CHAPTER 3 RESEARCH METHODOLOGY	52
3.1	INTRODUCTION.....	52
3.2	RESEARCH METHODOLOGY	53
3.2.1	<i>Action Research.....</i>	54
3.2.2	<i>Design Research.....</i>	55
3.2.3	<i>Comparing Action Research and Design Research</i>	55
3.3	THE “LEARNING ANATOMY WITH HAPTIC FEEDBACK SYSTEM” PROJECT	57
3.3.1	<i>Description of Participants.....</i>	58
3.3.2	<i>Surveys.....</i>	59
3.3.3	<i>System Evolution and Experimental Setting.....</i>	63
3.3.4	<i>System Development</i>	72
3.3.5	<i>Questionnaire Design in the Technology Acceptance Model</i>	78
3.3.6	<i>Questionnaire Design for LAHFS.....</i>	81
3.4	USER FEEDBACK.....	84
3.4.1	<i>Description of User Tests</i>	84
3.5	DATA ANALYSIS	86
3.5.1	<i>Quantitative Data Analysis</i>	86
3.5.2	<i>Qualitative Data Analysis - Thematic Analysis.....</i>	87
3.6	ETHICS APPROVAL	88
4	CHAPTER 4 DATA ANALYSIS	89
4.1	RESULT OF INITIAL SURVEY.....	89
4.2	STUDENT RATINGS OF LAHFS: VAS (QUANTITATIVE) QUESTIONS	91

4.2.1	<i>'Performed Well'</i>	92
4.2.2	<i>'System Useful'</i>	93
4.2.3	<i>'Easy to use'</i>	94
4.2.4	<i>'Mentally/physically stressed'</i>	95
4.2.5	<i>Correlations amongst VAS question ratings</i>	97
4.2.6	<i>'Would use/recommend the system'</i>	98
4.2.7	<i>'Quiz useful' and scores on quiz</i>	100
4.2.8	<i>Summary of findings on VAS questions</i>	102
4.3	GENDER, COURSE/UNIT OF STUDY, AND PRIOR EXPERIENCE WITH HAPTIC OR 3D INTERFACES	103
4.3.1	<i>Gender</i>	103
4.3.2	<i>Course/unit of study</i>	105
4.3.3	<i>Previous experience with haptic or 3D systems</i>	109
4.4	ANALYSIS OF LEARNING STYLE WITH SYSTEM V3	113
4.4.1	<i>Summary of learning styles with LAHFS</i>	115
4.5	ANALYSIS OF VARIOUS LEARNING ACTIVITIES AND RESOURCES	115
4.6	ANALYSIS OF QUALITATIVE QUESTIONS	118
4.6.1	<i>Qualitative Data Analysis - Thematic Analysis</i>	118
4.6.2	<i>Best aspects</i>	119
4.6.3	<i>Suggestions for improvement</i>	120
4.7	SUMMARY OF CHAPTER 4	120
5	CHAPTER 5 DISCUSSION	122
5.1	RESEARCH QUESTIONS AND DISCUSSION	122
5.2	RESEARCH QUESTION 1	126
5.2.1	<i>Discussion on results from the VAS questions</i>	127
5.2.2	<i>Concluding Remarks on RQ1</i>	132

5.3	RESEARCH QUESTION 2.....	135
5.3.1	<i>Gender.....</i>	136
5.3.2	<i>Course/unit of study.....</i>	137
5.3.3	<i>Prior experiences with haptic.....</i>	139
5.3.4	<i>Prior experiences with 3D.....</i>	140
5.3.5	<i>Learning styles.....</i>	141
5.3.6	<i>Concluding Remarks on RQ2</i>	143
5.4	RESEARCH QUESTION 3.....	143
5.4.1	<i>Elements of user acceptance</i>	144
5.4.2	<i>Concluding Remarks on RQ3</i>	145
5.4.3	<i>Relevance of LAHFS to the laboratory practical topic</i>	148
5.4.4	<i>Limitations of LAHFS and the Study.....</i>	149
6	CHAPTER 6 CONCLUSIONS AND FUTURE WORK.....	152
6.1	CONCLUSIONS AND CONTRIBUTIONS OF THE RESEARCH.....	152
6.2	RECOMMENDATIONS.....	157
6.3	SUGGESTIONS FOR FUTURE RESEARCH	157
	REFERENCES.....	160
	APPENDIX 1 – ETHICS APPROVAL DOCUMENTS	170
	APPENDIX 2 – COPY OF THE QUESTIONNAIRE INCLUDING VARK QUESTIONS.....	177
	APPENDIX 3 – USER TEST 3	184
	APPENDIX 4 - PAPERS PUBLISHED.....	188
	PUBLISHED IN THE PROCEEDINGS OF ASCILITE IN 2011	188
	PUBLISHED IN THE UNIVERSITY OF TASMANIA IN 2012.....	188
	PUBLISHED IN THE PROCEEDINGS OF THE E-LEARNING CONFERENCE IN 2013.....	188
	PUBLISHED TO INTERACTIVE TECHNOLOGY AND SMART EDUCATION (ITSE).....	189

Table of Figures

FIGURE 3-1 TIMING OF INITIAL SURVEY AND USER TESTS WITH 3 VERSIONS OF LAHFS.....	61
FIGURE 3-2 SYSTEM V1. DEFORMING OF THE LUNGS WITH HAPTIC FEEDBACK.....	66
FIGURE 3-3 SYSTEM V2. EXAMPLE OF LABELS OF CHAMBERS OF THE HEART AND BLOOD VESSELS.....	67
FIGURE 3-4 SYSTEM V3. EXAMPLE OF FLOATING MENU OPTION WITH SOME LABELS	67
FIGURE 3-5 SYSTEM V3. EXAMPLE OF A QUIZ QUESTION.....	68
FIGURE 3-6 USER TEST 1 (A) A USER TEST OF SYSTEM V1 (B) FILLING OUT THE SURVEY	69
FIGURE 3-7 USER TEST 2 AND 3.....	71
FIGURE 3-8 EXAMPLE OF VAS QUESTION ON QUESTIONNAIRE	81
FIGURE 4-1 COMPARISON OF VAS QUESTION ACROSS THE SYSTEM V1, 2 AND 3.....	91
FIGURE 4-2 PERFORMED WELL WITH THE SYSTEM	92
FIGURE 4-3 SYSTEM USEFUL	93
FIGURE 4-4 EASY TO USE THE SYSTEM.....	95
FIGURE 4-5 'MENTALLY STRESSED'.....	96
FIGURE 4-6 'PHYSICALLY STRESSED'.....	97
FIGURE 4-7 'WOULD USE' IN V2 AND 'WOULD RECOMMEND' IN V3.....	99
FIGURE 4-8 GENDER COMPARISONS	104
FIGURE 4-9 RESPONSES ON VAS QUESTIONS FROM FIVE DIFFERENT COHORTS ACROSS THREE SYSTEM VERSIONS.	105
FIGURE 4-10 RATING ON SYSTEM USEFUL BY MBBS1 AND CXA273 IN SYSTEM V3	107
FIGURE 4-11 RATING ON 'QUIZ USEFUL' BY MBBS1 AND CXA273 STUDENTS IN SYSTEM V3.....	107
FIGURE 4-12 QUIZ RESULTS BY MBBS1 AND CXA273 STUDENTS IN SYSTEM VERSION 3.....	108
FIGURE 4-13 USERS' RATINGS OF THE SYSTEM WITH DIFFERENT PRIOR EXPERIENCE LEVELS WITH HAPTIC ...	110
FIGURE 4-14 USERS' ASSESSMENT ON THE SYSTEM WITH DIFFERENT EXPERIENCE LEVELS WITH 3D.....	111

List of Tables

TABLE 3-1 SUMMARY OF PARTICIPANTS	59
TABLE 3-2 LABEL OF ORGAN PARTS	64
TABLE 4-1 CORRELATIONS (R) BETWEEN VAS QUESTIONS.	97
TABLE 4-2 STANDARD MULTIPLE REGRESSION: WOULD RECOMMEND, WITH VAS5 AND QUIZ USEFUL (UT3)	100
TABLE 4-3 CORRELATIONS OF INTENTION TO USE THE SYSTEM WITH OTHER VAS QUESTIONS.....	100
TABLE 4-4 CORRELATIONS (PEARSON'S R) BETWEEN VAS QUESTIONS ACROSS VERSIONS 1,2, AND 3.....	101
TABLE 4-5 CORRELATIONS (PEARSON'S R) BETWEEN VARK LEARNING STYLE PERCENTAGES AND VAS QUESTIONS.....	114
TABLE 4-6 CORRELATIONS (PEARSON'S R) BETWEEN VARK LEARNING STYLE PERCENTAGES AND VAS QUESTIONS AS WELL AS QUIZ RESULTS.	115
TABLE 4-7 MEAN AND MEDIAN RANKINGS OF EIGHT LEARNING RESOURCES	116
TABLE 4-8 QUALITATIVE COMMENTS	119

CHAPTER 1 INTRODUCTION

1.1 THESIS CLAIM

This thesis is the result of research work largely carried out by the candidate Ms Soonja Yeom, with the research training and assistance of three main PhD supervisors from different disciplines: Emeritus Professor Arthur Sale (Engineering and ICT), Dr Andrew Fluck (Education) and Dr Derek Choi-Lundberg (Medicine).

The thesis relies mainly on the principle of prior publication, and three papers are reproduced in the thesis in support of this claim, as well as an internally presented paper.

The main body of the thesis therefore provides the context to tie the papers together and to document the main findings, discussion, and future work, in more detail than could be included in the papers themselves.

1.2 PURPOSE OF THE STUDY

Gross anatomy is an important topic in many health-related disciplines, and is regarded as one of the most difficult to learn as well as resource-intensive to teach (Codd & Choudhury, 2011; Keedy et al., 2011). Although the usefulness of specific educational technologies may be controversial, technology in education is pervasive and the field is continuously advancing (Dominguese, 2011; Kinnison, Forrest, Frean, & Baillie, 2009). Haptic technology is improving, enabling haptic sensation/feedback to be provided as a useful element of a user interface. The aim of this study is to characterise undergraduate students' acceptance of a haptic interface in learning anatomy. Design Research and Action Research were adopted as the most suitable methodologies for this study.

1.3 DEFINITION OF TERMS

CXA273: Anatomy and Physiology 2. A subject taken by undergraduate students enrolled in a variety of courses such as Bachelor of Health Science, Bachelor of Exercise Science, Bachelor of

Chapter 2

Education, Bachelor of Human Movement, and Bachelor of Outdoor Education.

Gross Anatomy: The study of anatomy at the macroscopic level. This is the topic area of this research.

Haptic feedback or haptics: a combination of somatosensory (touch) sensation mediated by tactile receptors in skin, and kinaesthetic (muscle sense) sensation, mediated by kinaesthetic receptors in muscles, tendons, and joints (Panait, Akkary, Bell, Roberts, Dudrick, & Duffy, 2009).

LAHFS: Learning Anatomy with Haptic Feedback System, which the author developed and tested for this thesis.

MBBS: Bachelor of Medicine and Bachelor of Surgery course. All students enrolled in this course study Gross Anatomy in years 1 to 3.

TAM: Technology Acceptance Model, a model in understanding predictors of human behaviour toward acceptance or rejection of the technology.

VAS: Visual Analogue Scales, a measurement instrument that tries to measure a characteristic or attitude that is believed to range across a continuum of values and cannot easily be directly measured (Gould, Kelly, Goldstone, & Gammon, 2001).

1.4 RESEARCH FOCUS

The research spans the disciplines of ICT, Anatomy, and Education.

In broad terms the research aimed to explore acceptance of haptic (touch, force) feedback in a user interface by undergraduate university students learning anatomy. This broad aim is refined in *sections 1.5 and 2.8* to identify specific '*research questions*'.

1.5 STRUCTURE OF THE THESIS

The chapter structure of the thesis is as follows:

1. This *introduction* shows how the thesis is structured.
2. A *review of relevant literature* on user interfaces, haptic feedback, anatomy learning, and education. This provides rationale for the RQs (RQ1, What are the responses and attitudes of students toward a haptic interface for learning anatomy? RQ2, What user characteristics influence his/her learning from and acceptance of the haptic learning system? RQ3, What elements of the haptic learning system influence user acceptance?). The section informs the reader about how user

interfaces in general work and more specifically how haptic interfaces facilitate human-computer interaction and human learning

3. The *research methodology* used and its evolution during the course of the research. This addresses the 'What?' and 'How?' questions, and covers research methodology, LAHFS system software development, instruments for gaining user feedback, and data analysis.
4. An *analysis* chapter that contains more detailed results than could be provided in the published papers. The collected results from three user tests over 2 years were analysed, including student ratings of the LAHFS, overall and by various user factors including gender, course/unit of study, previous experience with haptic or 3D systems, and learning styles
5. A *discussion* of the most important findings synthesized from the foregoing and the papers, and put into the context of the related research literature.
6. Conclusions from the present study and suggestions for *future research*.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

How technology, computer technology in particular, has been used in education is examined in this chapter, particularly in the context of the discipline of gross anatomy at university level. Progress in haptic interfaces is examined, in medical related areas with an investigation of how it is advancing. It is done in anticipation of how the haptic interface option has been used as a learning tool for anatomy as well as ~~skills~~ for medical and surgical procedures. An examination is then conducted of how individual learning preferences in modes or styles impact on learning. Gender differences in learning preferences are also examined.

Technology has been used in learning for a long time in different educational levels and areas. However, the effect and necessity of technology in education has been controversial for many years. It provides many promises in theory, but there have been gaps between the technology and human users. Nevertheless, the area has grown and some areas, such as learning management tools, are now widely accepted and used.

2.2 TECHNOLOGY IN LEARNING - COMPUTER AIDED LEARNING

2.2.1 Brief History of Technology in Learning

The use of technology in learning has a long history, due to the common perspective about learning as a crucial and complex aspect of human life. The main purpose of this brief review on how the field of education has utilised different technologies over time provides a better viewpoint about the use of technology for anatomy learning.

Chapter 2

Digital technology was introduced for learning in the late 1950s, and debates on its efficacy started at the same time (Rogers, 2004; Säljö, 2010). Later Prensky (2001) coined the terms 'digital natives' describing the new generation who were born into a new culture immersed in digital technologies, and 'digital immigrants' describing previous generations who have lived in the analogue age and immigrated to the digital world. Prensky argued digital technology has changed the way 'digital native' students think and learn and is part of their life/being, while 'digital immigrant' teachers may have difficulties utilising available technology efficiently (Prensky, 2001).

As digital technology becomes an inescapable part of teachers' and students' lives, the key issue is how teachers can utilise this medium to enhance students' learning experiences (Elliott, 2008). Especially when one party is a digital immigrant and the other is a digital native. This research deliberately did not focus on the generation difference.

Personal digital technologies have developed from the introduction of personal computers and the Internet, to the present era of personal devices such as phones and tablets with wireless access to the Internet. As technology becomes more accessible and powerful, more images and dynamic media elements such as video and sound have been included in learning resources.

Technology enhances learning experiences with evident improvement of performance (Abbott et al., 2011; Burns, 2013; Kazley et al., 2013). Kazley and his colleagues (2013) reported perception on educational technology from health professions staff, academics and students at a medical university. The majority of students welcomed incorporating educational technology in their learning, whereas some academics remained sceptical.

As digital technology advances, the importance of interactivity was a key focus to make the resources useful and meaningful. Interactivity helps students understand and memorise better (Alessi & Trollip, 2001; Palombi, Pihuit, & Cani, 2011; Temkin, Acosta, Malvankar, & Vaidyanath, 2006; Wang, Hsu, Reeves, & Coster, 2014). Such interactivity can be achieved through active engagement, when resources to interact are provided (Beauchamp & Kennewell, 2010). Multimodal information for accurate evaluation of virtual training system was measured with user-centred design (Jia, Bhatti, Nahavandi, & Horan, 2013). This study reported enhanced performance via haptic/tactile interaction and suggested this mode of interface is particularly useful for the fields requiring a combination of visual and haptic work such as medical training.

Chapter 2

Collins & Halverson considered that differentiation was one of the great advantages of computer use in education (Collins & Halverson, 2010). Each student may have distinct topic areas to be explored, at different depth or breadth. Advantages of technology in learning are individualization, learning at one's own pace, possible repetition of the contents, hands-on, activity-based learning and different approaches in assessment (Burns, 2013; Collins & Halverson, 2010).

Learning resources designed carefully with multimedia design principles improve both long-term retention and long-term transfer of learning (Issa, Mayer, Schuller, Wang, Shapiro, & DaRosa, 2013; Issa, Schuller, Santacaterina, Shapiro, Wang, Mayer, & DaRosa, 2011). For example, multimedia design principles were used in a lecture to teach cardiac muscle knowledge to first year medical students in India (Ingole, Kumar, Bahattere, & Chaware, 2015). Results of 90% of the multimedia group were good to excellent compared to only 65% of the traditional resources group which used theoretical lectures only.

The use of technology in learning raises the possibility of repetitive and adaptive practice, because 'drill and practice' are important areas of certain academic subjects. Technology and its applications in learning and training will continue to advance, particularly multimedia to engage multiple senses of the user.

2.2.2 Multimedia in learning

Multimedia is defined as any object or work composed of two or more different elements such as still images, video, animation, sound and text (Chapman & Chapman, 2009; Grimes & Potel, 1991). Well-designed multimedia systems are used to enhance learning and have a long history of use within assistive technologies.

While the term 'multimedia' commonly denotes a technology, it also is used to suggest enhanced learning experiences (Alessi & Trollip, 2001). For example, spatial and multisensory learning produces improved spatial recall over time while also supporting the notion of transfer-appropriate processing (Vanags, Budimlic, Herbert, Montgomery, & Vickers, 2012).

Multimedia applications are used in many different areas such as animated training sequences which are more effective than a text manual (Abbott, Brown, Evett, Standen, & Wright, 2011). Multisensory options are widening including tangible technology which is a new approach where users interact with digital information through the physical environment by grasping and manipulating objects. Many results favour animations or multimedia, but the crucial point of applying them is the

content matter. One example of interactive multimedia tangible technologies is found in helping children with autism (Battocchi et al., 2008). An interactive tablet supporting multi-user interaction was used, which encouraged not only touch but also collaboration.

Users with a variety of levels of visual impairment were able to play a series of games using multimedia audio and haptic perception using a joystick with camera attached (Evreinova, Evreinov, & Raisamo, 2008), which was rated a robust and preferable input technique.

Several studies have found that multimedia CAL resources for anatomy are an effective supplemental resource for students (Kish, Cook, & Kis, 2013; Palombi et al., 2011; Saltarelli, Roseth, & Saltarelli, 2014; Sugand, Abrahams, & Khurana, 2010; Toth-Cohen, 1995). Kish and his colleagues (2013) found that the group with the CAL resource improved their performance significantly. Palombi's group had an intuitive way to present spatial relationships between objects. Additionally, learning resources in multimedia assist students' long-term transfer and long-term retention in medical education contexts (Issa et al., 2011).

On the other hand, the human cadaver laboratory offered a significant advantage over a model-based multimedia simulation tool (Saltarelli et al., 2014). This suggests that additional pedagogical strategies are required to align or incorporate multimedia simulation into learning tasks.

Another study found that the traditional condition group significantly outscored the multimedia group on delayed tests of retention (Issa et al., 2013). This might still be a controversial area, nevertheless CAL learning is certainly useful when the “best” option is not available. Also a best option of learning for some may not be the first preference for others. Thus, various options may provide a better accessibility to learning.

3D Models and Virtual Reality (VR).

Basic e-book versions of traditional anatomy textbooks and atlases use static 2D images; in contrast, some CAL resources provide fadable, layered 2D images allowing virtual dissection (Saltarelli et al., 2014) and/or rotatable 3D images (with or without stereoscopic viewing) for computers, tablets and smartphones with touch screens (Cornwall & Pollard, 2012; Lewis, Burnett, Tunstall, & Abrahams, 2014; Ponnampalam, 2013; Temkin et al., 2006; Yammine & Violato, 2015). Such novel methods were useful due to possible educational benefits (Cornwall et al., 2012).

A 3D environment is another potential element of a multimedia learning setting. For example, an interactive 3D multimedia module had higher satisfaction, acceptance, and was more enjoyable than 2D images (Keedy et al., 2011). Similarly, there was a greater preference for 3D computer models compared to 2D images by junior doctors, although there were no differences in learning between groups randomised to 2D vs 3D resources

Chapter 2

(Tan et al., 2012). A meta-analysis of 36 studies found that 3D images are superior to 2D methods in spatial and factual anatomical knowledge (effect sizes $d=0.50$ and $d=0.30$, respectively), and user satisfaction and perceived effectiveness are also higher with 3D resources (Yammine & Violato, 2015).

Comparing 3D CAL resources with dissection has produced mixed results, either similar performance on spatial anatomical knowledge (Codd & Choudhury, 2011) or worse performance from 3D CAL resources on identification and explanation questions (Saltarelli et al., 2014). Benefits of learning anatomy in virtual reality environments include cost saving for repetitive practices, more flexible access, and choice of individual preference of learning mode (Lewis et al., 2014; Nguyen, Nelson, & Wilson, 2012; Nicholson, Chalk, Funnell, & Daniel, 2006; Ponnampalam, 2013).

Multimodal and Multisensory.

Using multimedia content to assist learners improves student learning experiences and understanding, because the more senses are engaged, the greater the chance of influencing the learner's brain (Black, Segal, Vitale, & Fadjo, 2012).

Chapter 2

Multisensory learning can be more effective in encoding, storing and retrieving experience and knowledge (Shams & Seitz, 2008) and this may allow individuals to learn in many different ways (Walling, 2014), and hence benefit learning (Black, Segal, Vitale, & Fadjo, 2012). There were significant positive differences in learning by visual and tactile learners when the learning resources were designed accordingly (Gorjian, Alipour, & Saffarian, 2012).

As haptic technology advances, how this modality can help education by combining with more established multimedia needs investigation. Haptic feedback contributes to learning spatiotemporal skills which have a force sensitive component (Amirkhani & Nahvi, 2016). Participants internalised and recalled better abstract motor skills (a sequence of forces in one dimension) when the haptic paradigm was combined with the visual paradigm rather than presented via either modality alone (Morris, Tan, Barbagli, Chang, & Salisbury, 2007; (Wu et al., 2014). This is because spatial and multisensory learning produces improved spatial recall over time while also supporting the notion of transfer-appropriate processing (Blikstein, 2013; Vanags et al., 2012). In order to achieve better learning and/or transferable practice, effective interface design with multi-sensory interaction is important. It will reduce learning error by reducing the load on short-term cognitive processes (Seok et al., 2010). Multimodal interaction is becoming a more effective method for learning and is more

widely used as advanced technology becomes affordably available (Blikstein, 2013; Sigrist, Rauter, Riener, & Wolf, 2013). How users and/or students perceive the technology used in their learning, especially with more modes available, is another topic area for further research.

How multimodal systems that include haptic technology are used and support learning will be investigated in the next section.

2.2.3 Haptic Technology in Learning

The scope of research on haptic interfaces has included scientific visualization, assistive technology for visually and physically impaired users, general medical training, and surgical training. For example, a computer assisted surgical planning tool was developed and evaluated by Schwartzman, Salisbury, Silva, & Girod (2014); A small number of experts in the field, only three surgeons, tested the system and reported that the system was easy to learn and use that they would be comfortable to integrate it into their practice. The system featured a bimanual sense of haptic feedback, which is more realistic in surgery. Another example is used for catheter insertion training with tip-force measurement sensors which provide deformation as feedback (Tercero et al., 2013). Catheter tip tracking and deformation were measured in this study. Different groups

used different interfaces (i.e. haptics interface, computer interface, and manual injection. Conclusion was that the haptic interface trial measured deformation of the artery model successfully. The approach enables the training simulators to be enhanced through haptic teleoperation with a notable outcome to this.

Learning is more useful and effective if done through more than one sensory organ with concurrent feedback (Shams & Seitz, 2008; Sigrist et al., 2013). The addition of a haptic interface improves surgical training value over traditional methodologies, as “touch is more important than sight” in the surgical context (Esteban, Fernández, Conde, & García-Peñalvo, 2014) and advantages of CAL are confirmed. The use of haptic interfaces improves “the performance of the students, during the first stage of their education. Using haptic simulators, surgical training is more effective than other methods because it helps in the development of psychomotor skills” (Esteban et al., 2014).

Some terms such as tactile, kinaesthetic, or haptic, are used frequently in research on haptic interfaces. Tactile perception is the sense of touch, such as a pattern pressed upon an individual’s skin. Haptic feedback includes a combination of somatosensory (touch) sensation mediated by tactile receptors in skin, and kinaesthetic sensation, mediated by kinaesthetic receptors in muscles, tendons, and joints which detect the

Chapter 2

position and movement of parts of the body or forces upon them (Panait et al., 2009; Sigrist, Rauter, Riener, & Wolf, 2013; Tercero, Najdovski, Ikeda, Nahavandi, & Fukuda, 2013; Ullrich & Kuhlen, 2012; Wu et al., 2014), and it is this that we use on an everyday basis to explore and understand our surroundings (Challis, 2013).

Much of the literature talks about haptic technology as a different modal interface which produces a positive result which is not easy to achieve otherwise. This stimulates research to find out if a haptic interface option may be effective or not in another subject area. Different types of learners may be assisted by different interface modalities when accessing learning materials. Since a study on the effectiveness of interactive haptic interface for undergraduate engineering students found a higher (21%) than control group and 18% higher in comparison with their own pre-test in learning achievement (Amirkhani & Nahvi, 2016), this study examines a similar interface in a different discipline. However, these findings may not be generalisable to other contexts. A systematic evaluation and comparison with real-life complexity may be required to assess designs using a haptic interface modality (Sigrist et al., 2013). A focused area of study may be beneficial at least for the particular subject, determining for example whether a haptic interface is effective for learning anatomy.

2.3 EDUCATIONAL THEORY ABOUT TECHNOLOGY

2.3.1 Educational Theories

Although there are a number of educational theories about technology, only those relevant to the research are discussed in this section.

Constructivism views learning as a building process in which new knowledge is actively constructed upon prior knowledge. Learners take an active role and knowledge is based on active experience (Huang, Rauch, & Liaw, 2010). Problem-based Learning (PBL) is based upon constructivism, and “PBL had a positive effect on students’ satisfaction, ability to apply knowledge, and/or ability in clinical problem solving” (Bergman et al., 2013).

Many CAL resources for anatomy are designed based upon multimedia design principles and cognitive load theory, with non-redundant images, text, and auditory information integrated to take advantage of the user’s parallel cognitive processing of visual and auditory information and multisensory learning mechanisms (Ayres, 2015; Clark & Mayer, 2003; Shams & Seitz, 2008; van Merriënboer & Sweller, 2010). Cognitive load theory acknowledges a limited working memory, with the implication that cognitive load should be minimised during the learning process. For

example, illustration alone is better than illustration and text, but if text is essential for intelligibility, placing it nearby or on the illustration (spatially contiguous) and keeping it to a minimum is recommended to reduce cognitive load (Paas, Renkl, & Sweller, 2003).

How technology can be a useful tool is further investigated based on Technology Acceptance Model (TAM), which will be elaborated more in the following section.

2.3.2 Technology Acceptance Model

The Technology Acceptance Model (TAM), introduced by Davis (1986), is an adapted model of the Theory of Reasoned Action (TRA). TRA considers a person's performance of a specified behaviour to be determined by his or her behavioural intention to perform the behaviour. TAM provides a basis for tracing the impact of external factors on internal beliefs, attitudes, and intentions to help prediction and explanation of acceptance of technology (Davis et al., 1989). TAM posits that **perceived usefulness** and **perceived ease of use** are primary elements for computer acceptance behaviours. An interesting finding from Davis (1989) was 'usefulness' has a stronger influence than 'ease of use' on people's intention to use a system, although the ease of use variable had a significant effect on intention to use.

The original TAM has been expanded beyond Davis's (1989) original conceptions of perceived usefulness, perceived ease of use, and user acceptance of information technology. The TAM model has subsequently underpinned numerous studies including that by Marangunić and his colleagues (2015), which confirm its broad applicability to various technologies. Variant variables were added and studied by many researchers such as Turner and colleagues who added behavioural intention to use (BI) (Turner, Kitchenham, Brereton, Charters, & Budgen, 2010). Measurement of user intention to use the system was elicited by two questions used on different versions of the survey in this current study.

Technology that is likely to be accepted by users needs to be integrated into the existing curriculum through new and/or redesigned tasks to enhance the users' learning experiences and hence their outcomes (Fluck, 2003; Puentedura, 2010). The variety of learning resources available for learning anatomy are discussed next.

2.4 RESOURCES IN LEARNING ANATOMY

Anatomy is an important subject in medical related studies. There are numerous learning options for anatomy including textbooks, lecture

Chapter 2

notes, lab sessions with cadaveric dissection, prosected specimens, interactive multi-media resources such as CDs or DVDs, plastic models, radiological imaging including radiographs, CT, and MRI, surface anatomy, and body painting (Marker, Juluru, Long, & Magid, 2011; McNulty, Sonntag, & Sinacore, 2009; Mustafa, Allouh, Mustafa, & Hoja, 2013; Nguyen et al., 2012; Tan et al., 2012; Weber, Hincke, Patasi, Jalali, & Wiper-Bergeron, 2012; Choi-Lundberg, Low, Patman, Turner, & Sinha, 2015; S Yeom et al., 2013).

Cadaveric dissection is regarded as the gold-standard learning option in anatomy by many commentators. Cadaveric dissection is the closest to the real, living human body in terms of understanding three-dimensional anatomical spatial relationships in multiple senses, including tactile experiences (Saltarelli et al., 2014; Shaikh, 2015). Other commentators argue that surface anatomy of a living human being is preferable (McNulty et al., 2009), but this does not allow detailed appreciation of anatomical relationships amongst deeply placed structures. However, difficulties with learning through cadaver dissection include the difficulty of access to the resources, moral and ethical issues, cost, logistics, safety, and students' reactions including attitudes towards death and dying and future patients (Preece, Williams, Lam, & Weller, 2013; Thomas, 2013).

Chapter 2

The Virtual Human Project (Ackerman, 1998) generated serially sectioned images of the entire body, which were released in 1994 (male) and 1995 (female). Similar datasets of Asian bodies were released in 2002 and 2003 by China, followed by Korea (Park et al., 2005). These datasets enable the building of 3D volume-rendered representations, with the potential for virtual dissection, which could eliminate many of the issues with cadaveric dissection discussed above.

Many reports on CAL resources and their the positive roles in anatomy curricular improvement have been published (Codd & Choudhury, 2011; Dominguese, 2011; Yeom et al., 2013; Kish et al., 2013; Lewis et al., 2014; McNulty et al., 2009; Palombi et al., 2011; Ponnampalam, 2013; Schvartzman, Salisbury, Silva, & Girod, 2014; Yushkevich et al., 2006). Some (Lewis, McNulty) concentrated more on an individual's learning approaches (see more in section 2.6 Learning Styles); others, such as Palombi (2011), focused more on the interactive interface. Many including Ponnampalam (2013) attempted to provide better ways to identify key anatomy structures and their complex spatial relationships than traditional resources.

In contrast with the above studies, Preece and colleagues (2013) reported that learning with a physical model had a higher achievement (86%) than with textbooks (63%) and a virtual 3D reconstructed computer model

Chapter 2

(64%). The students' feedback rated positively in the physical model and the 3D computer model. It is possible that the advantage of the physical model included the touch sensation it provides; the 3D computer model lacked haptic feedback. If physical interaction has benefits, this could be provided by a haptic interface, which could provide a better learning environment.

As understanding the complex spatial relationships between organs is crucial in anatomy learning, and virtual 3D environments can provide this information (Ponnampalam, 2013). Codd and Choudhury (2011) found that technology-enabled 3D anatomy learning (they called it virtual reality anatomy learning) is used to compliment traditional methods of learning effectively.

Students' important factors for selecting CAL resources were cost, self-assessment opportunities, user friendliness, alignment with curriculum, and good graphics (Choi-Lundberg et al., 2015). Additional factors in another study were to prepare for examinations and understand anatomical relationships (Marker et al., 2011), in other words, spatial relationships among organs as mentioned above.

By adding an additional sensory modality of haptic feedback, anatomical these spatial relationships might be more effectively mastered because of the additional interaction dimension.

2.5 HAPTIC TECHNOLOGY IN MEDICAL AREAS

Using all our senses is the natural way we interact with and learn from the world. Multimodal feedback in human-computer interactions is being used more widely due to technological advances. A recent study (Sigrist et al., 2013) has revealed that concurrent multimodal feedback can be effective if the task to be learned is complex; specifically, visuohaptic feedback can be effective for spatiotemporal learning, with improved short-term retention.

We may apply the same technology in learning, anticipating that it should enhance learning experiences. As technology assists to depict key anatomical structures and their complex spatial relationships by providing 3D models and interactivity, a haptic interface may further improve available learning options and experiences. Haptic interfaces have not replaced current practice, but may provide additional learning resources that would be beneficial in anatomy education. As Dede (1996) concluded, “keeping a balance between virtual interaction and direct interchange is important”. He continued, “Technology-mediated

Chapter 2

communication and experience supplement, but do not replace, immediate involvement in real settings”.

Student acceptance of and learning from CAL resources incorporating haptic feedback have been evaluated in various advanced medical procedural contexts. For example, performance of complex laparoscopic surgery tasks is improved by provision of haptic feedback compared to no haptic feedback (Panait et al., 2009). Medical residents rated virtual dissection of a temporal bone simulator using a Phantom Omni haptic device similar to plastic models, but lower than cadaveric temporal bone dissection (Fang, Wang, Liu, Su, & Yeh, 2014). All medical students as well as residents in this study agreed that the simulation helped the comprehension of the selected temporal bone anatomy by improving average comprehension score significantly from before to after training with the simulation. Students trained only on HapTEL virtual teeth performed as well as those trained on traditional manikins with plastic teeth (Arevalo et al., 2013). Most first year veterinary students who used a ‘haptic cow’ rectal palpation simulator agreed that it was useful for learning the feel and locations of anatomical structures (Kinnison et al., 2009). Post-graduate surgical trainees using a 3D stereoscopic virtual reality system with haptic interface (CyberTouch gloves) improved their knowledge of inguinal canal anatomy more than the traditional 2D

resources group, and rated the system higher on engagement, ease of use, and learning spatial relationships (Sakellariou et al., 2009).

Visual display of deformation is another important feedback to provide haptic interface to the user. One particular feedback for this is force measurement and deformation technique (Choi, Sun, & Heng, 2003; Tercero et al., 2013; Ullrich & Kuhlen, 2012). A deformable model based on propagation process was proposed as early as 2003 (Choi et al., 2003) and the practical uses of the technique with Phantom Omni are occurring in various medical related areas, as overviewed above, since then.

2.5.1 Anticipated benefits of haptic feedback in learning anatomy

Physical anatomical models can be explored with sight and touch, and improve spatial anatomical understanding more than textbooks and CAL resources without haptic feedback (Preece, Williams, Lam, & Weller, 2013). Touch and kinaesthetic sensation through feeling and manipulating real human tissues is available in anatomical training through studying cadavers, prosected specimens, and living human models (Dev et al., 2002; McLachlan & Patten, 2006), and is particularly important for surgical and procedural training (Dev et al., 2002). Thus, adding haptic feedback devices and software to CAL resources has been an active area of research and development for two decades, including for

surgical training (Dev et al., 2002; Fang et al., 2014; Hoffman & Vu, 1997; Panait et al., 2009; Ruthenbeck & Reynolds, 2015), clinical procedural training (Arevalo et al., 2013), palpation training (Howell, Conatser, Williams, Burns, & Eland, 2008), and anatomical education (Dev et al., 2002; Ingole et al., 2015; Khot, Quinlan, Norman, & Wainman, 2013; Kinnison, Forrest, Freaan, & Baillie, 2009; Lewis et al., 2014; Sakellariou, Ward, Charissis, Chanock, & Anderson, 2009; Weber et al., 2012).

Haptic feedback is especially valuable in surgical and medical procedure training and related anatomy, engaging kinaesthetic feedback in learning specific motor skills. These procedures typically involve instrument-based rather than direct-touch procedures; hence, a stylus-based haptic device can provide high fidelity haptic feedback. In contrast, in anatomy learning from cadavers, prosected specimens, or anatomical models, touching and manipulating objects with all fingers of both hands cannot be replicated with high fidelity with a stylus-based haptic interface. These factors likely contributed to the earlier adoption of haptic interface virtual training in surgical applications rather than anatomy, in addition to the high cost of haptic devices. However, as the cost of technology drops and haptic interfaces improve, diffusion of the technology will enable students to learn anatomy with haptic systems. If some students learn better with tactile/haptic stimulation, it can be an alternative and beneficial interface option for them.

2.5.2 Interactive Interface

Interactivity is key to achieving benefits of technology in education. Furthermore, it is important that alternative options are available for flexibility for different learners or in different circumstances. An interactive interface is the crucial factor for improved learning and this is facilitated when learners have an active role in their learning (Kirschner, Kester, & Corbalan, 2010).

After 20 years of advancement in the technology of learning, the role of technology remains as a useful tool rather than replacing an existing learning setting. There is therefore scope for investigating the learning benefits of using haptics in learning anatomy, given the availability of relatively inexpensive haptic interface devices. The responses of anatomy students to such a system will be a key indicator of its usefulness in learning anatomy in haptics. This provides a rationale for the first research question:

RQ 1: What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy?

2.6 HAPTIC DEVICES, AND THE PHANTOM OMNI AS AN EXAMPLE

Types of feedback/sensory input that are provided to the user will be examined, and how these relate to learning with the Phantom Omni as an example of a haptic interface. The Phantom Omni measures 3D spatial position (along x-, y- and z-axes) and the orientation (roll, pitch and yaw) of its handheld stylus, and uses motors to create forces that push back on the user's hand to simulate touch and interaction with virtual objects. Degrees of freedom are 6, and Degrees of force feedback are 3.

The device used in this study is Phantom Omni. It has been previously used for tele-surgery for catheter insertion, the result was assessed as "deformation was successfully measured" in the haptic environment (Tercero et al., 2013). Also many more medical studies with Phantom Omni including Teklemariam et al. (2015) and Tercero et al. (2013) were found. Teklemariam and Das (2015) experimented and explained how beneficial integrating virtual reality and haptic feedback in product development was with a computer-aided design (CAD) model. Bryan and his team have used a similar to this as early as 2001, but with a more complex version of the device (Bryan, Stredney, Wiet, & Sessanna, 2001).

Chapter 2

The areas of use of haptic devices include palpation, needle insertion, (Thomas, 2013), endoscopy, endovascular procedures and arthroscopy (Benyahia, Van Nguyen, Chellali, & Otmane, 2015; Ullrich & Kuhlen, 2012). For example, a study used haptic palpation with a multi-object force algorithm to support multiple layers of anatomy and a pulse force algorithm for simulation of an arterial pulse with Phantom Omni with an extra pad attached to it (Howell et al., 2008; Ullrich & Kuhlen, 2012).

Real time response is essential in haptic feedback. This requires rapid processing using a reasonably powerful computer. Our visual system recognizes 25-30 interlaced images/frames per second as a smooth video, but haptic perception requires a significantly faster rate. As Coles et al. (2011) suggested, "The required refresh rate to provide realistic force feedback is commonly accepted to be at least 1000 Hz". This higher frequency requires a more powerful computer processor. Therefore, the greater realism comes at a cost in resource terms. A "fast and accurate collision detection is crucial in any VR-based surgery simulation system" in an advanced environment (Wu et al., 2014). The tactile and visual feedback needs to be integrated as well as fast.

It is clear the nature of the system itself will be a crucial determinant of the efficacy of any haptic device used for learning anatomy. There will be external elements of the system immediately apparent to the learner, and

internal design conditions which are hidden. The design complexity of the learning system is such an internal condition. This leads to the third research question:

RQ3: What elements of the (haptic) learning system influence user acceptance?

(RQ2 is below)

2.7 OTHER FACTORS AFFECTING LEARNING AND USER

ACCEPTANCE – LEARNING STYLES AND GENDER

2.7.1 Learning Styles

Understanding learning preferences and styles of an individual is important in order to provide more suitable resources and learning experiences to fit an individual's needs (Lewis et al., 2014; McNulty et al., 2009). Conveying anatomical information to the user in the most appropriate manner for an individual's learning style is crucial (Lewis et al. 2004). Both less anxiety and improved clinical performance were reported when students studied in their learning style preference (Boström & Hallin, 2012).

Chapter 2

The term 'learning styles' has been used since 1950s, but there have been different views on its meaning. Due to the disagreement on the definition, there are many different tools to measure different constructs, including, for example, the Meyers Briggs Type Indicator (MBTI), Kolb's learning style Inventory, Dunn and Dunn learning style model (Boström & Hallin, 2012), visual (V), aural (A), reading/writing (R), and kinesthetic (K) VARK test (Fleming, 1995), and others.

Different learning styles or preferences in individual learners may have an influence on learning. In order to investigate how different types of learners accept haptic interfaces in simulations, the VARK instrument was used in the present study. The VARK instrument is described in the next section.

2.7.2 The VARK tool

Fleming's (1995) VARK instrument identifies people's preferences for visual (V), aural (A), reading/writing (R), and kinesthetic (K) sensory modalities. It consists of 16 questions with four options each. Each option relates to one of the four particular sensory modalities, so that the modality (or modalities) selected more frequently is more preferred (See Appendix 2). Leite and his colleagues (2009) investigated validity, reliability and dimensionality of the VARK tool in depth using its

psychometric properties; their analysis supported the VARK tool as an instrument for identifying learning preferences. The VARK instrument has also been found to have adequate validity and reliability specifically with medical students (Nuzhat, Salem, Quadri, & Al-Hamdan, 2011).

2.7.3 Gender difference in User Acceptance

Gender differences of university students for user acceptance were examined in the framework of the Technology Acceptance Model (Terzis & Economides, 2011; Padilla-Meléndez et al., 2013). There was a report on gender differences of university students in the framework of the Technology Acceptance Model (TAM) with Internet-based courses (Padilla-Meléndez, del Aguila-Obra, & Garrido-Moreno, 2013). Students' attitude toward a technology and the intention to use it were examined in the addition of another element, 'perceived playfulness' in Padilla-Meléndez's study. It reported that there was gender difference not only with the element of perceived playfulness but also preferring element as usefulness by male and ease of use by female. Terzis and Economides (2011) agreed on that males were more motivated by 'usefulness' and influenced by social environment, and females were more motivated by exam preparation, playfulness, and 'ease of use'. However, these differences were not statistically significant.

However another research reported that there is a difference in genders, both in perception and acceptance of e-learning (Ong & Lai, 2006). The study involved six international companies and each developed their e-learning systems for their own context. It is suggested that females are more significantly influenced by their perception of ease of use whereas males are influenced more on usefulness when they accepted a system. Another study about computer-based assessment from Terzis and Economides (2011) agrees with the result of Ong and Lai.

While the system itself will affect learning efficacy (RQ3), equally the nature of the learner will also be important. Some of these characteristics have been explored here, and appear to be the most likely factors which might influence learning from and acceptance of the system.

RQ2: What user characteristics influence their learning from and acceptance of the haptic learning system: VARK learning styles, especially kinaesthetic learners; gender, prior experience with haptic / 3D interfaces, and course/unit of study?

2.8 RESEARCH QUESTIONS

Chapter 2

There are growing numbers of studies on how a haptic interface is accepted in surgical training, but not many studies have been done in anatomy learning, and on how undergraduate students respond to a haptic interface for learning anatomy in particular. Understanding what elements of the system and characteristics of the users make them accept the system is the aim of this thesis. The study has been framed around the following three research questions:

RQ1: What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy?

RQ2: What user characteristics influence their learning from and acceptance of the haptic learning system: VARK learning styles, especially kinaesthetic learners; gender, prior experience with haptic / 3D interfaces, course/unit of study

RQ3: What elements of the haptic learning system influence user acceptance?

CHAPTER 3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter discusses the decisions made and the processes used in the research to examine acceptance of the haptic learning system by undergraduate students.

As we had seen in the literature review section, the haptic technology has advanced with the particular device for a while. But that was mainly in the surgery area. Now we would like to see what kind of acceptance we can see from the same device in a related but slightly different subject area – anatomy. Also if that would be acceptable by a students with different learning preferences and/or different individual factors such as gender, courses of their study, etc.

It thus describes the overall research methodology. Action Research and Design Research are two main methodologies this study adopted, and

analysis of the results was done both with quantitative and qualitative data analysis. The research design and processes, such as how the system was implemented and how three user tests were developed, are explained in this chapter.

The research questions were addressed as the system evolved through three versions of increasing complexity in response to user feedback and learning theory.

3.2 RESEARCH METHODOLOGY

The project is multidisciplinary, incorporating Computer Science, Medicine, and Education and therefore collaboration amongst technologies, practitioners, and the researcher is crucial (Reeves, 2000, 2006). Refinement and further development of system versions and research approaches was undertaken throughout the project in a cyclic fashion, moving between the disciplines.

Research may have more than one function; for example, Plomp (2009) described eight different functions. Out of the eight functions he identified, this research includes part or all from the following two functions: “actions research (to design/develop a solution to a practical problem), and design research (to design /develop an intervention [such

as programs, teaching-learning strategies and materials, products and systems] with the aim to solve a complex educational problem and to advance our knowledge about the characteristics of these interventions and the processes to design and develop them)" (ibid. p.12). Thus, Action Research and Design Research were selected as the prime methodologies of the research to investigate.

3.2.1 Action Research

Action Research is an integration of educational research with teaching and learning practices (Page, 1994). It combines action and reflection, and theory and practice (Brydon-Miller, Greenwood, & Maguire, 2003). Dickie and Jay (2010) stated "the cyclical nature of action research ensures that improvement to both teaching and learning is ongoing throughout the process", by quoting Mills (2000) and Brydon-Miller, Greenwood and Maguire (2003).

Action research includes the cyclic approach of planning, acting, observing, and reflecting which adopts a revised theory at each rotation (Lingard & Kennedy, 2010; Coghlan & Brydon-Miller, 2014). Action researchers aim to create and build a broader connection across disciplinary divides.

3.2.2 Design Research

'Design Research' is variously called 'design-based research' (Anderson & Shattuck, 2012), 'design research' (Reeves 2010) and 'development research' (Oh & Reeves, 2010), but 'Design Research' is the term used in this thesis.

Design Research includes educational design process in a cyclic and iterative approach with analysis, design, evaluation and revision activity (Collins, Joseph, & Bielaczyc, 2004; Hjalmarson, Nelson, & Lorie; Plomp, 2009) and this practice of Design Research is aimed at developing an optimal solution for a main content – which is learning anatomy in the present study.

Design Research allows for staged implementation and retesting of the system. In this study, LAHFS was improved over three cycles incorporating user acceptance and comments at each stage.

3.2.3 Comparing Action Research and Design Research

Both research methods may be suitable to adapt for this project, and further clarification on how different aspects of each research method fit to the study will be examined in the section.

Action Research and Design Research are similar in terms of their cyclic approach. However, the focus of Action Research is a participatory process of research and practice, frequently used in educational contexts. It is also defined as bringing together action and reflection, theory and practice, and it may include participation with others. Then it is sub-defined as participatory action research (Brydon-Miller et al., 2003).

As the researcher was not involved in teaching anatomy, so lacked the participatory aspect common in this approach. Furthermore, the external perspective of several varied cohorts of learners offered an opportunity to generalise findings to a wider population. Although this research aimed at acquiring new knowledge initially and Action Research was a particular approach that may have been used, this study wanted to acquire new knowledge from a variety of cohorts, so Action Research was not the most suited one to this study. Therefore Action Research was not adopted in its entirety, but contributed towards the methodology.

On the other hand, Design Research focuses on the development process in terms of iteration towards an outcome. Design Research also focuses on educational technology (Oh & Reeves, 2010). This research is more focused on the use of technologies and their applications in the learning domain. An important aspect of Design Research is the effect of previous iterations on the construction of the system at the centre of the study. In

that context, Design Research was a better fit and this was adopted. Analyses were also undertaken in early stages of the research in order to inform subsequent decisions.

Thus, this research, involving the development and evaluation of user acceptance of a haptic system to assist the learning of anatomy, draws more heavily on Design Research methodology, while incorporating elements of Action Research in terms of developing a system for a specific educational context (undergraduate-level anatomy) in a cyclic manner in response to user (participant) feedback. Problem definition and identification of improvement were done in the initial survey, and conceptual design was also done at this stage. This software and hardware improvement from stage to stage was key, and made the Design Research approach a better fit to the study.

3.3 THE “LEARNING ANATOMY WITH HAPTIC FEEDBACK SYSTEM” PROJECT

A system designated ‘Learning Anatomy with Haptic Feedback System’ (LAHFS), was built for this study. It provides haptic feedback on different organs of the body using a stylus. This prototype includes liver, lungs, heart, and major blood vessels, and is not intended as a comprehensive tool, but rather a test vehicle for the research. In this chapter the features

and development will be described with its evolution through cycles of development.

3.3.1 Description of Participants

Undergraduate students in selected courses or units at the University of Tasmania were invited to participate in the user test sessions via an email or learning management system announcement. Participants were students in the Bachelor of Medicine and Bachelor of Surgery (MBBS, medical students), Bachelor of Computing (BComp, computing students), or the unit CXA273 Anatomy and Physiology 2 (various courses including Bachelor of Health Science, Biomedical Science, Exercise Science, and Education; allied Health and Education students).

A total of 89 students participated in user tests for system versions 1, 2, and 3, including 58 males and 31 females. The mean and median ages of the users were 21 and 20 years, respectively. The majority of the participants were enrolled in the Bachelor of Medicine and Bachelor of Surgery course ($n=59$), with the remainder in the Bachelor of Computing ($n=10$), and the unit CXA273 Anatomy and Physiology 2 ($n=20$) who are enrolled in Health Sciences and Education Bachelor courses. Demographic information is shown in Table 3-1.

Table 3-1 Summary of Participants

		System v1	System v2	System v3
Number of participants		18	27	44
Course or unit of study		MBBS2/3 (8)	MBBS1 (27)	MBBS1 (24)
		Computing (10)		CXA273 (20)
Male		15	17	26 (12 MBBS1 + 14 CXA273)
Female		3	10	18 (12 MBBS1 + 6 CXA273)
Age (years): Mean, median, range		23, 22, 19-33	20, 19, 18-31	21, 20, 18-26
Previous experience with haptic	Not at all	14	26	34
	Not more than 10	4	0	7
	More than 10	0	1	3
Previous experience with 3D	Not at all	1	9	16
	Not more than 10	5	9	21
	More than 10	12	9	7

3.3.2 Surveys

3.3.2.1 Initial Survey

Prior to implementation and development of the first version of the system, an interview was conducted with an Anatomy Lecturer, followed by a survey with 23 (12 female and 11 male) 3rd year medical students on

Chapter 3

March 10, 2011 to collect information from key stakeholders. The main questions asked were

1. *What aspects of learning anatomy do you find most difficult?*
2. *What are your usual resources to study anatomy? Why do you use these?*
3. *What are the limitations of these resources?*

The results from the survey were analysed and reported in section 4.1.

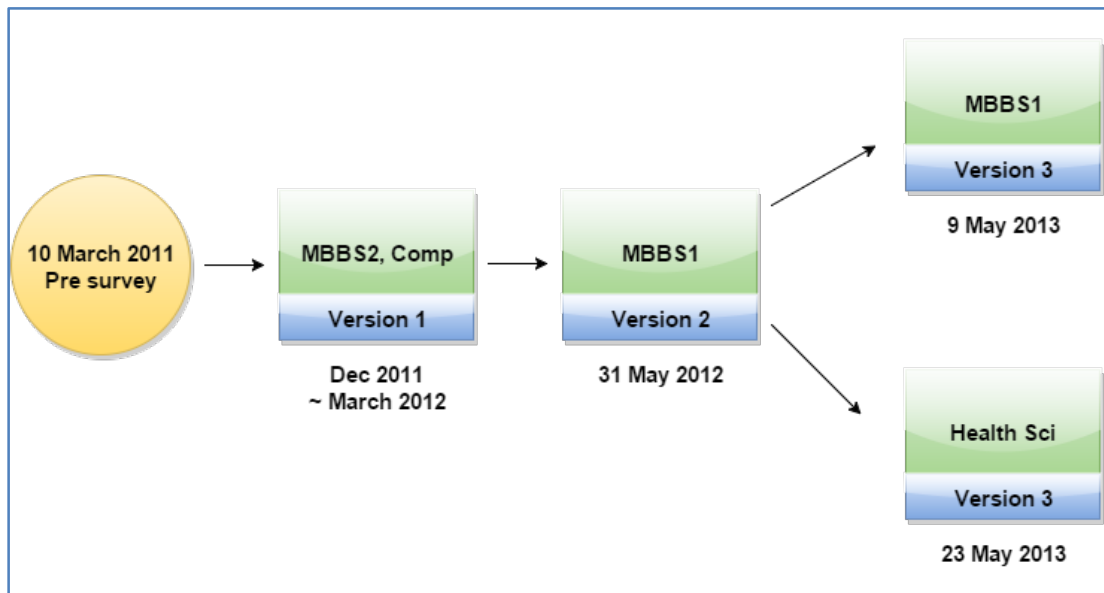
According to the feedback from the students, also confirmed with the literature, that similar experiments have been conducted in the surgery field, but not yet for anatomy.

The main purpose of the survey was to determine if another type of learning resource in anatomy would benefit some or all medical students.

3.3.2.2 User tests

The first user test was run on several occasions between December 2011 and March 2012. The second user test was on May 31st 2012. The 3rd user test was on May 9th and May 23rd in 2013 (Figure 3-1).

Figure 3-1 Timing of initial survey and user tests with 3 versions of LAHFS



Version 1 was with year 2 and 3 medical students (the system was set up in a tutorial room, participation through email invitation) and computing students in the period from Dec 2011 to March 2012. This version was designed to see the initial responses from users with two selected organs with different density (liver and lungs). The anatomy content was limited to enable computing students to test the system without being daunted by complex anatomy.

Version 2 was done with year 1 medical students during the practical session on prenatal development including organogenesis of cardiovascular, respiratory and digestive systems on 31 May 2012. They had a previous practice session three weeks earlier (10 May 2012) on gross anatomy of organ systems including cardiovascular, respiratory and digestive systems.

Chapter 3

The content was expanded to align with learning objectives for 1st year medical students.

Version 3 was run twice with two different cohorts: one with year 1 medical students on 9 May 2013 during a practical on gross anatomy of organ systems including cardiovascular, respiratory and digestive. The other one was with CXA273 Anatomy & Physiology 2 students on 23 May 2013 during a practical in week 12 on renal system anatomy. Practicals earlier in the semester were on cardiovascular, respiratory, and digestive systems.

3.3.2.3 The LAHFS system development

The Software Development Life Cycle and the Waterfall Model in particular were used for developing and implementing the LAHFS system. This included identifying system requirements, software requirements, preliminary design based on analysis, program design, code and debug, test and pre-operations, operations and maintenance in an iterative procedure between successive steps (Bassil, 2012; A. M. Davis, Bersoff, & Comer, 1988; Royce, 1970).

The cyclic process of Design Research is very similar to systems development life cycle in software development. As a multi-disciplinary project, it is practical to take the approach that has a similarity in both

areas, i.e. designing an educational system and a software system development.

3.3.3 System Evolution and Experimental Setting

The level of anatomical detail in the system aligns better with the year 1 medical students' expected knowledge, so these students rather than 2nd and 3rd year students were recruited to test the system for system versions 2 and 3. The permission of the Anatomy Lecturer was obtained to set up the system at one station of a practical laboratory session on Introductory Anatomy during regular class time. The system was relevant to the learning objectives of the practical.

System version 3 incorporated a quiz involving identification of anatomical structures, to further improve the potential pedagogical value of the haptic system. There were two different user groups: 1st year medical students (a different cohort from user test 2) and students enrolled in CXA273 Anatomy and Physiology 2, a unit including study of the cardiovascular, respiratory and digestive systems. Thus, both groups of students were studying topics related to the anatomical content of the system version 3.

Chapter 3

The first version had 1 module, the second version had 2 modules, and the third version had 3 modules (see Table 3-2):

- Version 1: The liver and the lungs (module 1) were implemented, mainly focusing on the different haptic feedbacks from these organs.
- Version 2: Module 1, plus module 2 added with the heart chambers (left atrium, left ventricle, right atrium, right ventricle), and 17 labelled blood vessels, i.e. 23 labelled structures in total.
- Version 3: Module 1, module 2 with four additional labels for blood vessels (venae cavae replaced with separate labels for superior vena cava and inferior vena cava), and module 3, a quiz with 10 questions requiring identification of named structures from module 2. An additional function of a floating sub-menu to move to another module was added in this version.

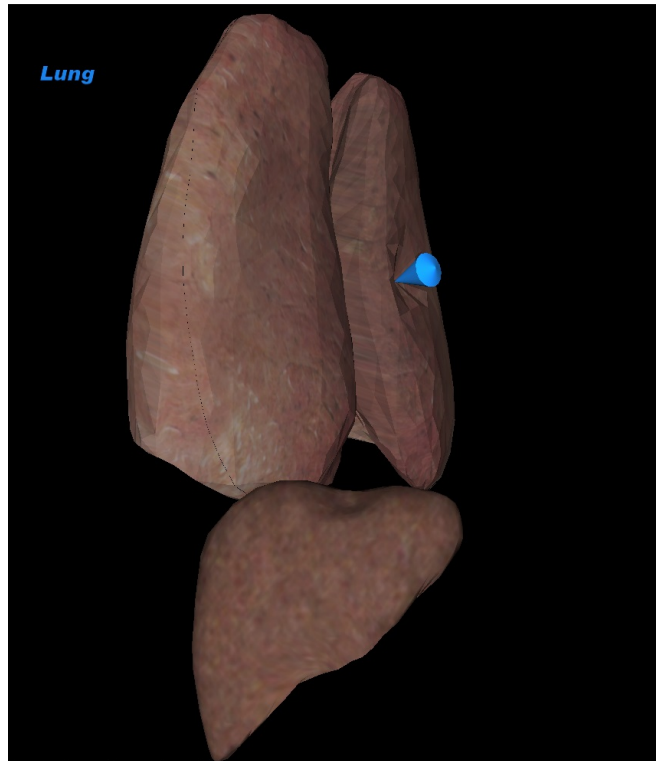
Table 3-2 Label of organ parts

Version 1 (2 labelled structures)	Version 2 (23 labelled structures)	Version 3 (27 labelled structures)
Module 1	Module 1	Module 1
Lungs	Lungs	Lungs
Liver	Liver	Liver
	Module 2	Module 2
	Left atrium	Left atrium
	Right atrium	Right atrium
	Left ventricle	Left ventricle
	Right ventricle	Right ventricle
	Arch of aorta	Arch of aorta

Chapter 3

Version 1 (2 labelled structures)	Version 2 (23 labelled structures)	Version 3 (27 labelled structures)
	Aorta	Ascending Aorta
		Descending Aorta
	Brachiocephalic trunk	Brachiocephalic trunk
	Right subclavian artery	Right subclavian artery
	Right common carotid artery	Right common carotid artery
	Left common carotid artery	Left common carotid artery
	Left subclavian artery	Left subclavian artery
	Left subclavian vein	Left subclavian vein
	Left internal jugular vein	Left internal jugular vein
		Left brachiocephalic vein
	Right subclavian vein	Right subclavian vein
	Right internal jugular vein	Right internal jugular vein
		Right brachiocephalic vein
	Venae cavae	Superior vena cava
		Inferior vena cava
	Pulmonary trunk	Pulmonary trunk
	Right pulmonary arteries	Right pulmonary arteries
	Left pulmonary arteries	Left pulmonary arteries
	Right pulmonary veins	Right pulmonary veins
	Left pulmonary veins	Left pulmonary veins
		Module 3
		<p><u>A quiz</u>: A randomly generated list of 10 structures to identify from module 2</p> <p>An additional function of a <u>floating sub menu</u> to move to another module was added in this version.</p>

Figure 3-2 System V1. Deforming of the lungs with haptic feedback



Chapter 3

Figure 3-3 System V2. Example of labels of chambers of the heart and blood vessels

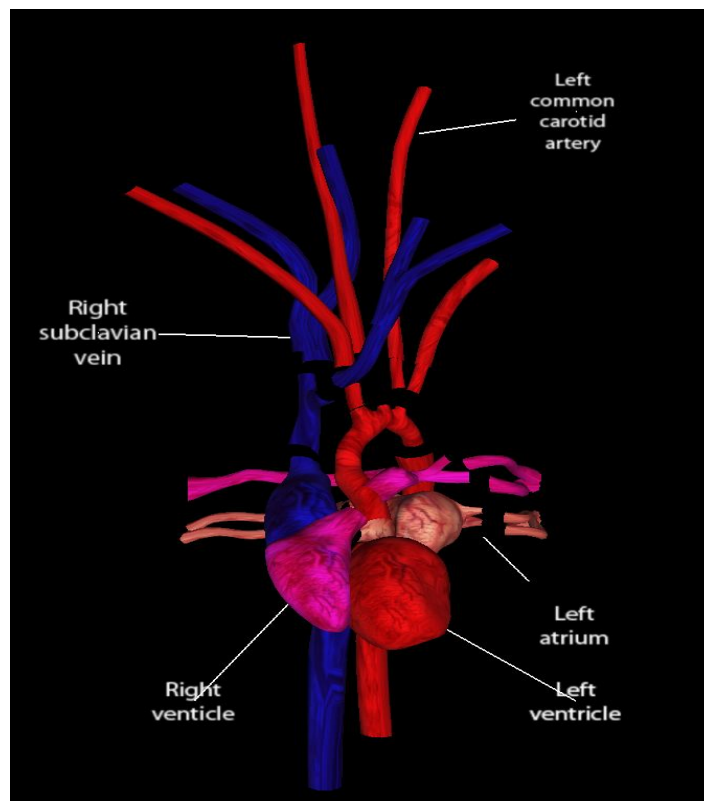


Figure 3-4 System V3. Example of floating menu option with some labels

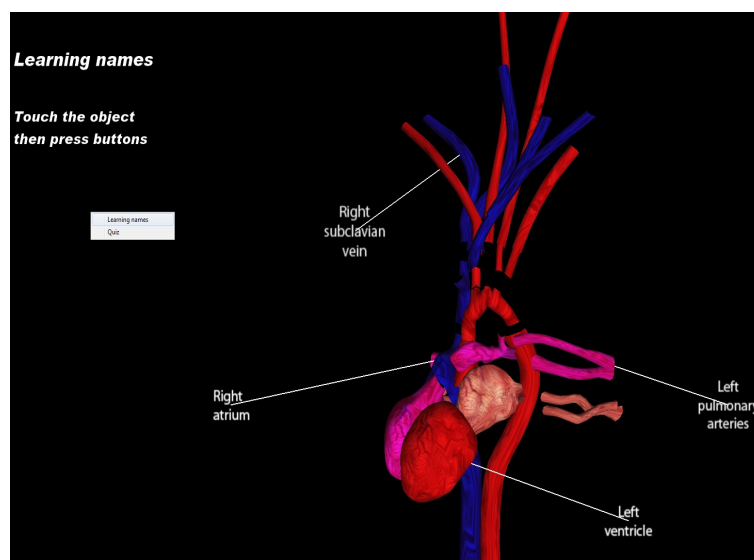
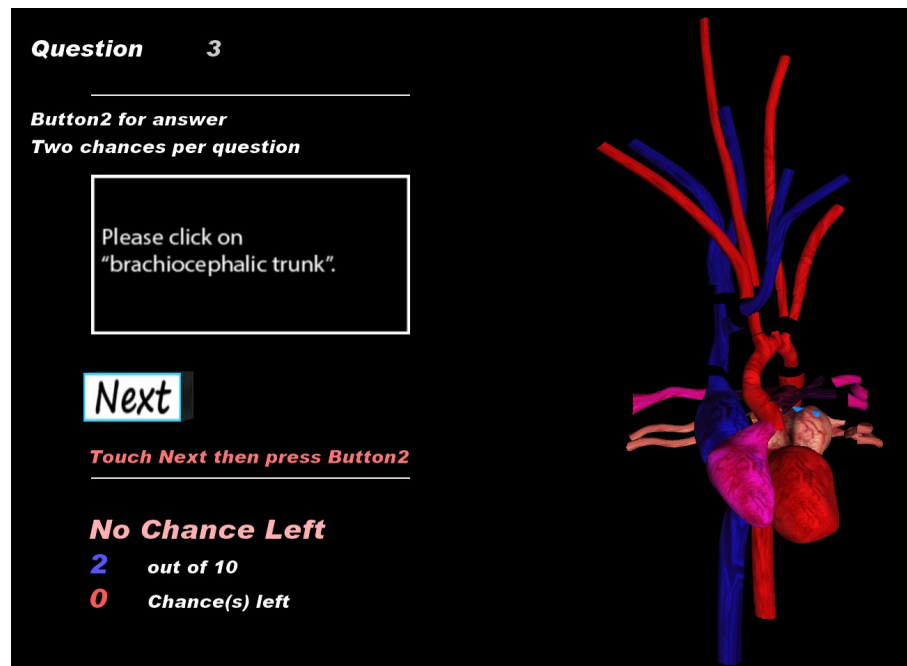
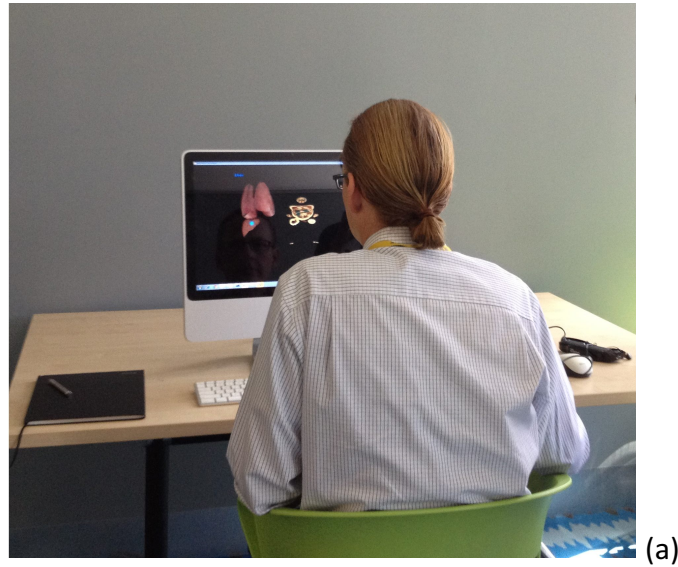


Figure 3-5 System V3. Example of a quiz question



Different environmental settings for the user tests were used as the project advanced. The LAHFS system was set up in a tutorial room in the Medical Sciences Precinct (Figure 3-6) and in an office in the Centenary Building for the first user test where participants from the medical student and computing student populations, used the system. Participants were invited to participate via email (medical students) or in person (computing students)(Yeom, 2011). Basic features of a haptic device were implemented all throughout the three versions such as selecting, grabbing, and moving the selected organ, and poking or touching the organ to experience the feel of the selected part. Zooming in and out was a rather intuitive function provided by grabbing an organ to draw it closer or further using the stylus's z-motion.

Figure 3-6 User Test 1 (a) a user test of system V1 (b) filling out the survey



The second version included a second module with the heart chambers and blood vessels, including 23 named structures (Table 3-2). One of buttons was enabled for selecting an object to move and/or rotate it, and the other for displaying the name of the organ. Haptic features such as structures' elasticity and rigidity, vibration feedback when moved organs touch each other, moving and rotating objects through 360 degrees to

view from any angle, zooming in and out, and friction responses were added on top of the first version.

The third version, in addition to the two learning modules described above, introduced a randomly generated set of quiz questions from the structures of module 2 (Table 3-2). Each question had a maximum of two attempts to answer. If the first try was successful then the system proceeded to the next question. Otherwise, the user had another chance to pick an organ or to pass the question and proceed, or move to another module via the floating sub-menu.

For the user tests of the second and the third versions, students were invited via email and an announcement on the learning management system and a reminder at the beginning of the class to participate in the research project by testing the haptic device during the anatomy practical (Figure 3-7). For medical students in user tests 2 and 3, the LAHFS system was set up at one of five stations (laboratory benches with a variety of learning resources) during the “integrated practical” anatomy learning session. The students rotated through the five stations, examining the resources provided while answering questions on a worksheet. The LAHFS system was set up at the station on the cardiovascular system; thus, the LAHFS system, which included the heart and major blood vessels

Chapter 3

amongst other organs, was related to the learning objectives of the station and the overall practical.

Figure 3-7 User Test 2 and 3



Another photo of the Lab (source: <http://www.utas.edu.au/health>)

In user test 3, another user test session with health sciences and education students enrolled in CXA273 was accomplished. A separate station was set up for the LAHFS system during an anatomy practical learning session on the urinary system. The organ systems of LAHFS did not correspond to the topic of the practical; however, previous practicals in the semester related to the organ systems included in LAHFS (respiratory, digestive, and cardiovascular). This lab session had about 15 minutes of a formal setting of lecture time with video watching followed by a short discussion time which was different to the MBBS lab sessions.

3.3.4 System Development

3.3.4.1 Software Development Environment

The system was developed with Visual Studio 2010 in C++ with the OpenHaptic API, which was open source. The core OpenHaptics toolkit is C based; some of the utility libraries use C++. 3D images of organs were received from HITLab NZ in 2011 from a postgraduate student project. A Phantom Omni robotic tool provided haptic feedback with six degrees of freedom and utilised the OpenHaptics Toolkit (Itkowitz, Handley, & Zhu, 2005) to interact with the anatomical visualisation data (Yeom 2011).

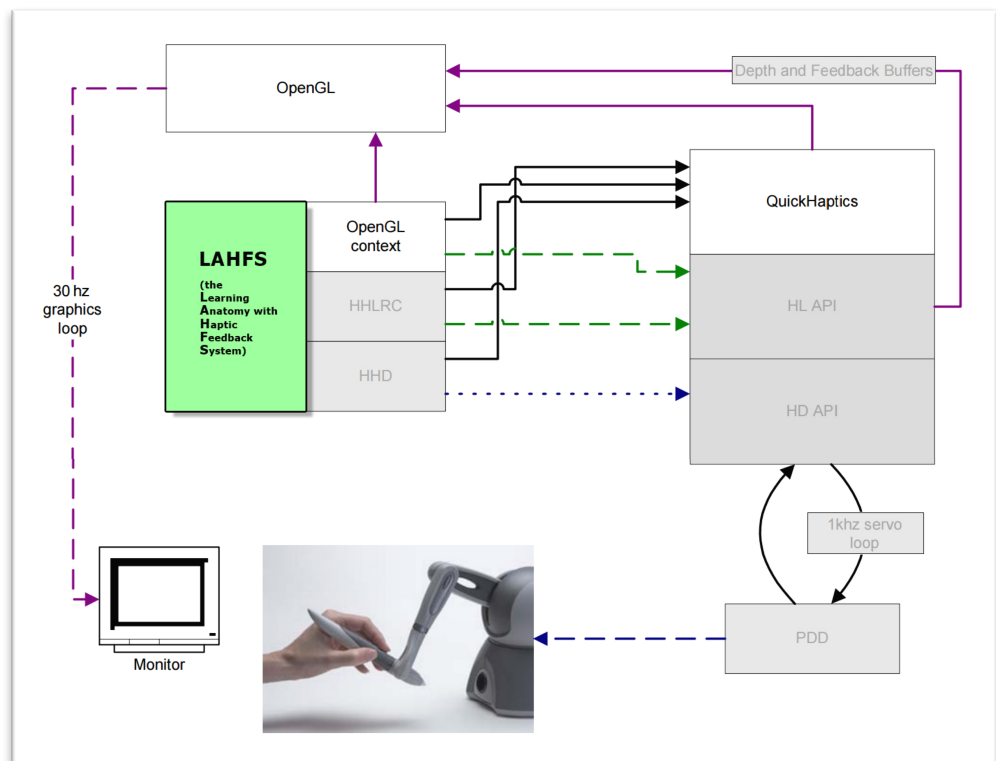
Chapter 3

The QuickHaptics™ micro API is implemented in the C++ programming language and makes use of the Standard Template Library.

The OpenHaptics toolkit includes the following:

- The Phantom Device Drivers (PDD),
- The QuickHaptics micro API (Figure 3-8) is the main API of OpenHaptics.
- The Haptic Device API (HDAPI) that works for initialization of the Phantom Omni device and updating the state of it as it moves (get state, set state, synchronize state)
- The Haptic Library API (HLAPI) regarding the stiffness and friction, shape rendering, effect rendering, that means generating haptic feedback, utilities, and source code examples.

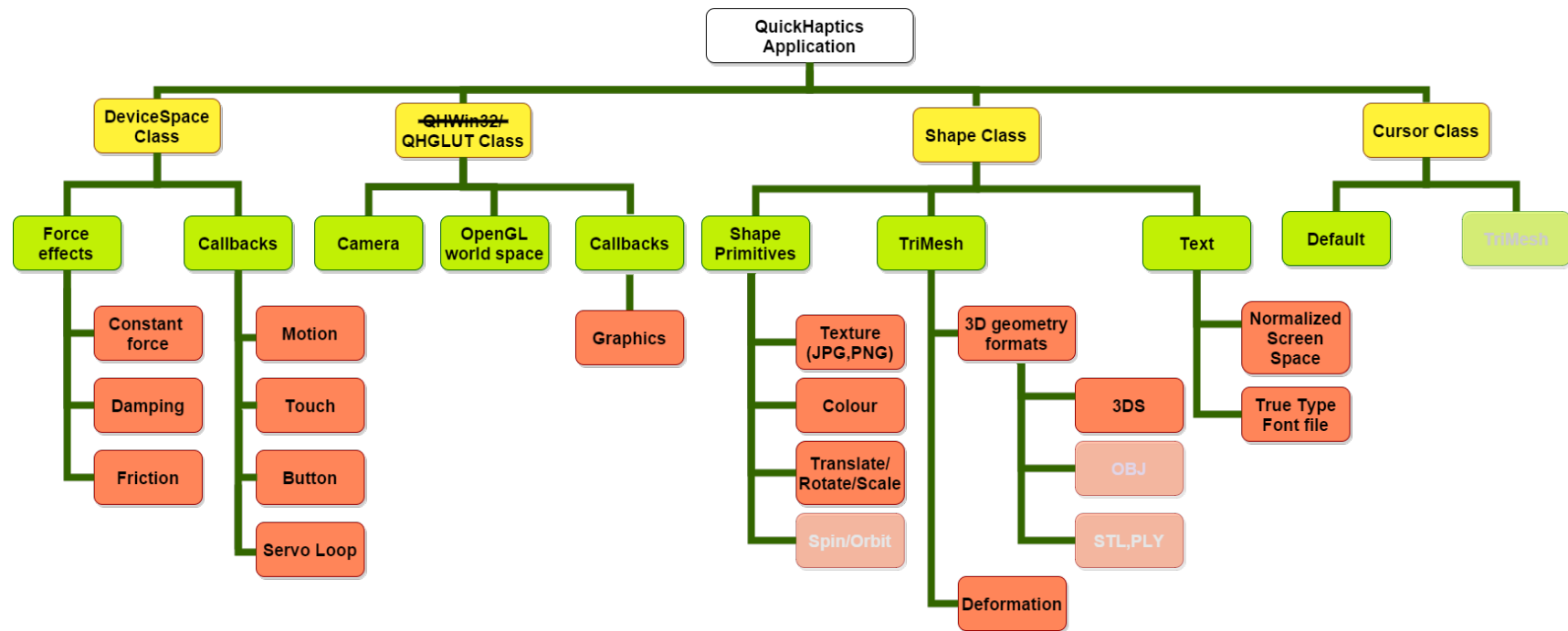
Figure 3-8 Implementing environment of LAHFS (modified from the user manual)



3.3.4.2 Implementation of LAHFS

Based on QuickHaptics with OpenGL, all the methods and their properties were used to implement LAHFS except greyed out properties (Figure 3-9), i.e. Spin/Orbit, OBJ, STL/PLY, TriMesh for cursor. Out of two options of QHWin32 and QHGLUT classes, the LAHFS system used QHGLUT to support Mac OS as well as Windows, QHGLUT is OS independent while QHWin32 API only works with Microsoft Windows. However there is a limitation of QHGLUT that it does not support multiple sub windows.

Figure 3-9 Implemented classes and properties for LAHFS (modified from the user manual)



3.3.4.3 System Hardware and Device

The development environment was upgraded throughout progress of the project. The computer system used in user test 1 was an Intel[®] Core[™] Duo CPU @ 2GHz, RAM 2GB. An upgraded system was used in user tests 2 and 3, which provided more sensitive feedback to the user. Its specification was Intel[®] Core[™] i7-2600 CPU @ 3.4GHz, RAM 16GB.

The version of Phantom Omni that was used for the LAHFS system supports 30 Hz of refresh rate for the frame and 1000 Hz haptics updates (OpenHaptics[®] Toolkit version 3.0) which met the required level suggested by Coles and colleagues (Coles, Meglan, & John, 2011).

IEEE 1394 FireWire card was installed into a PC, interfacing the haptic feedback device (Phantom Omni) with the PC. Phantom Device Drivers (PDD) was used to control the communication of the device with the computer.

The interface domain in this study comprises 3D modelling and 3D interface space with the Phantom Omni haptic device (Figure 3-10), which provides six degrees of freedom: three for position (x, y, z) and one each for pitch, yaw and roll (rotation in the forward vertical, horizontal and transverse planes). Force feedback gives different amounts of resistance

to an input depending on the state of the virtual operation (Yeom et al. 2013).

There are some specifications that LAHFS used such as force feedback workspace is $> 160W \times 120H \times 70d$ mm, hand movement pivoting at wrist, backdriven friction < 0.26 N, maximum exerable force at nominal orthogonal arms position is 3.3 N, continuous exerable force is $> 0.88N$, stiffness of X axis > 1.26 N/mm, Y axis > 2.31 N/mm, Z axis > 1.02 N/mm, inertia (apparent mass at tip) is about 45g. Position sensing is x,y,z (digital encoders) and stylus gimbal is pitch, roll, yaw ($\pm 5\%$ linearity potentiometers).

Figure 3-10 Phantom Omni Haptics device (Yeom, 2011)



3.3.5 Questionnaire Design in the Technology Acceptance Model

The questionnaire was designed based on the Technology Acceptance Model (TAM). TAM was introduced by Davis (1986) based on the theory of reasoned action and the theory of planned behaviour in psychology. It

then evolved to a model in understanding predictors of human behaviour toward acceptance or rejection of the technology (Marangunić & Granić, 2015).

According to TAM, Behavioural Intention to Use (BI) determines computer usage. BI is jointly determined by the person's Attitude toward using the system (A) and perceived Usefulness (U) (F. D. Davis, Bagozzi, & Warshaw, 1989). TAM treats Usefulness (U) and Ease Of Use (EOU) as two fundamental and distinct constructs (F. D. Davis et al., 1989; Shroff, Deneen, & Ng, 2011). Reliability differences were also found for other study characteristics, including reliability type, subject experience, and gender composition (Hess, McNab, & Basoglu, 2014).

Two different questionnaire formats, VAS and Likert, were considered based on the element of TAM. A visual analogue scale (VAS) was originally developed by Freyd in 1923 and used in a survey to measure the level of agreement to a statement between 0 and 100. Knapp (2013) compared VAS and Likert, highlighting their strong and weak points. 32% of respondents said that the visual analogue format was the easiest and 22% of respondents liked it as the second best format.

The discussion whether in some questions a VAS or a Likert scale should be used was tackled in 1987 by Guyatt et al., showing a greater improvement in the VAS and a greater variability in the improvement on

VAS compared to the Likert scale. The goals of the study were to assess the validity and reliability of the subjects' satisfaction VAS score and suggested that a VAS system is perhaps more suitable for satisfaction measurement.

One of the groups who had improvement in their heart symptoms showed different results from five-point, seven-point Likert or VAS scale in the comparative study (Pang et al., 2014). Thus the researchers concluded that using one scale to capture the entirety of the symptom might be insufficient. Also Guyatt and his colleagues did a comparative study and they showed a greater improvement in the VAS and a greater variability in the improvement on VAS compared to the Likert scale (Guyatt, Townsend, Berman, & Keller, 1987). Although the seven-point Likert was recommended, they believe that the responsiveness does not differ in the form of seven-point Likert or VAS.

Various studies have concluded that VAS has sufficient evidence for its validity and reliability (Brokelman et al., 2012; Davey, Barratt, Butow, & Deeks, 2007; Pang et al., 2014). Brokelman and his colleagues (2012) suggested that VAS is more suitable for satisfaction measurement. VAS is a simple and frequently used method to measure satisfaction or pain, both of which are hard to measure.

3.3.6 Questionnaire Design for LAHFS

Three different versions of the questionnaire were used in user tests 1, 2 and 3, with minor modifications in the wording and additional questions as the research project progressed.

The questionnaire included demographic questions on age, gender, prior experience with haptic devices and 3D computer interfaces, as well as visual analogue scale (VAS) questions (scale 0 to 100, see example in Figure 3-8) on their experiences with the LAHFS system. The questions included:

- Were you performing well with the system?
- Was the system useful?
- Was it easy to use the system?
- Did you get mentally stressed using the system?
- Did you get physically stressed using the system?

Figure 3-8 Example of VAS question on questionnaire

1. Were you performing well with the system?

Very poor Very well

0 50 100

--	--	--	--	--	--	--	--	--	--

Chapter 3

An additional VAS question relating to future use or recommendations was added in the system v2 and v3 user tests:

- Would you use this system as an aid of learning when it is fully developed? (Version 2)
- Would you recommend the university use a system based on this one? (Version 3)

A VAS question relating to the quiz was added in the system v3 user test:

- Was the quiz useful as a check on understanding?

(Refer to Appendix 2 for comparisons of questionnaires)

The users were invited to add any open-ended comments in system v1 and v2. The questionnaire used with system v3 was expanded with specific open-response questions:

- What were the best aspects of the system?
- What aspects of the system were most in need of improvement?
- What suggestions do you have for improvement?
- What other features would you like to see in the system to aid your learning?

Questionnaire (user test 3)

1. Were you performing well with the system?
2. Was the system useful for exploring the anatomical region?
3. Was it easy to use the system to explore the anatomical region?
4. Did you get mentally stressed while using the system?
5. Did you get physically stressed while using the system?
6. Would you recommend the University use a system based on this one?
7. Was the quiz useful as a check on understanding?

Open questions:

8. What were the best aspects of the system?
9. What aspects of the system were most in need of improvements? What suggestions do you have for improvement?
10. What other features would you like to see in the system to aid your learning?

Rank the following learning sessions or learning resources 1 (most useful) to 8 (least useful). In the case of the tactile (haptic) interface system you just trialled, consider its potential usefulness to you in relation to other resources you currently use. If you did not use one or more of the resources, write N/U (not used).

- ___ Lectures / tutorials / practicals (in-class learning)
- ___ Lecture / tutorial / practical notes
- ___ Anatomy software (please specify _____)
- ___ Anatomy websites (please specify _____)
- ___ Anatomy textbooks (including eBooks)
- ___ Anatomy atlases
- ___ A tactile (haptic) interface system such as the one you just trialled
- ___ Other resources (please specify _____)

In system v3 user tests, participants were also asked to rank a variety of anatomy learning sessions or resources including the LAHFS system from 1 (most useful) to 8 (least useful), and complete Neil Fleming's VARK

Chapter 3

questionnaire version 7.2 (Fleming, 1995) to determine their VARK Learning Style preferences for the categories Visual (V), Aural (A), Read/write (R), or Kinaesthetic (K). The VARK questionnaire was accessed from the site (<http://vark-learn.com/the-vark-questionnaire/>) with permission granted via an email on 18 June 2015 from Neil Fleming (Fleming, 2015; VARK Learn Limited, 2016)

It consisted of 16 questions with 4 multiple choices for each. The modality which received highest scores was the preferred sensory modality. As multiple selections are permitted, multiple modalities can be obtained.

3.4 USER FEEDBACK

3.4.1 Description of User Tests

3.4.1.1 User Test 1

- The participant was given the participant information sheet to read and sign, and asked if s/he had any questions.
- After a brief explanation/demonstration of the system, the participant was invited to try the system (lungs & liver).
- The participant was given the UT1 questionnaire to complete (see Appendix 2)

3.4.1.2 User Test 2

- The participant was given the participant information sheet to read and sign, and asked if s/he had any questions.
- After a brief explanation/demonstration of the system, the participant was invited to try the system.
- The participant was given the UT2 questionnaire to complete (see Appendix 2)

3.4.1.3 User Test 3

- The participant was given the participant information sheet to read and sign, and asked if s/he had any questions.
- After a brief explanation/demonstration of the system, the participant was invited to try the system (lungs & liver, followed by heart and vessels). The participant was informed that there would be a formative quiz on identifying structures after exploring and using the system for as long as the participant wished.
- The participant was then asked to complete a quiz with 10 identification questions randomly chosen from the labelled structure list. The participant was given up to two chances to answer each question, and the researcher recorded whether the response was correct or incorrect. Also the monitor image was recorded for further analysis.

- The participant was given the UT3 questionnaire, which included the VARK questionnaire, to complete (see Appendix 2)

3.5 DATA ANALYSIS

This study adopted a mixed-methodology approach to collect and analyse the data collected through the questionnaires.

3.5.1 Quantitative Data Analysis

3.5.1.1 Graphical presentation of data and statistical analysis

IBM SPSS Statistics Version 22 and Microsoft Excel for Mac 2011 were used for quantitative analysis.

Bar graphs show mean and standard deviations (Figure 4-1). Boxplots follow the usual convention of the horizontal line within the box indicating the median (50th percentile), and the upper and lower ends of the box indicating the 75th and 25th percentiles, respectively (the interquartile range, IQR). The whiskers extend to the highest and lowest scores that are not outliers, with outliers defined as being more than 1.5 times the IQR above the 75th percentile or below the 25th percentile, and

shown as 'o'. Extreme outliers more than 3 times the IQR above or below the IQR are shown as '*'.

T-tests or Mann-Whitney U tests were used to compare two samples, e.g., between two versions, two courses of study within one user test, or by gender. One-way Analysis of Variance (ANOVA) or Kruskal-Wallis one-way ANOVA were used to compare three or more samples, e.g., across three versions, participants' course of study, or prior experience with 3D systems. For post-hoc comparisons following ANOVA, Gabriel's post-hocs were used for unequal group sizes, Games-Howell if the equal variance assumption was violated, or Mann-Whitney U after Kruskal-Wallis ANOVA.

Parametric statistical tests were used if skewness, kurtosis, and Shapiro-Wilk tests of normality were all $p > 0.05$. If there was only mild departure from normality in one group, with one or more tests $0.025 < p < 0.05$, both parametric and non-parametric results are reported. Non-parametric tests were used if one or more normality tests were $p < 0.05$ in two or more groups, or if one group had one or more test $p < 0.025$.

3.5.2 Qualitative Data Analysis - Thematic Analysis

For the qualitative data analysis, Thematic Analysis was used to focus on identifying patterned meanings across a collected qualitative data set (Braun & Clarke, 2006).

To identify themes in this open question data, two researchers independently examined the texts. Common ideas were tabulated according to their frequency of occurrence. This produced a table (Table 4-8) in ranked order.

3.6 ETHICS APPROVAL

Due to the involvement of human subjects in the user tests, the project required approval from the Human Research Ethics Committee (Tasmania) Network (HREC).

An application was submitted on 4 April 2011, and was approved on 16 May 2011 as H00011743 (Appendix 1: Ethics approval).

As the project advanced, an amendment was submitted in April 2013 including changes to the title from “User acceptance for learning anatomy with augmented reality in 3D” to “User acceptance for learning anatomy with a tactile (haptic)”, along with revisions to the information sheet, consent form, and questionnaire, approved on 29 April 2013. (Appendix 1: Ethics approval – Project title changed).

The final report was submitted to the HREC on 8 December 2014.

CHAPTER 4 DATA ANALYSIS

4.1 RESULT OF INITIAL SURVEY

General consensus was found from the initial survey. This data was an encouragement for developing this system. The meeting with the lecturer and the collected initial survey identified the same type of difficulties.

Results of the initial survey are as follows:

The most difficult aspect of learning anatomy:

- *Visualization of what they have learned in lectures, 2D materials are not easy to reconstruct in 3D world*
- *Visualizing and applying anatomy practically in the clinical environment*
- *Anatomical relationships: separate organs may be understood but understanding their relationships to surrounding structures is challenging*

Chapter 4

- *Dissection of cadaver is complicated and confusing, with only limited time access*

Students' preferences for additional anatomy learning resources:

- *3D versions of images from textbooks or atlases*
- *Interactive software in 3D, with zooming and rotation*

Current practices based on survey:

- *Main resources of learning anatomy are textbooks, images from textbooks, radiological images (radiographs, CT, MRI), and computer based images, integrated practical sessions (self-directed worksheets are used with anatomical models that can be dissembled & reassembled), and cadaver dissection*
- *The anatomy program in the medical students' course at the University of Tasmania has been described in detail elsewhere (Choi-Lundberg et al., 2015)*

According to the content of a lab session for year 1 medical students, the thorax and the liver (in the abdomen) were selected.

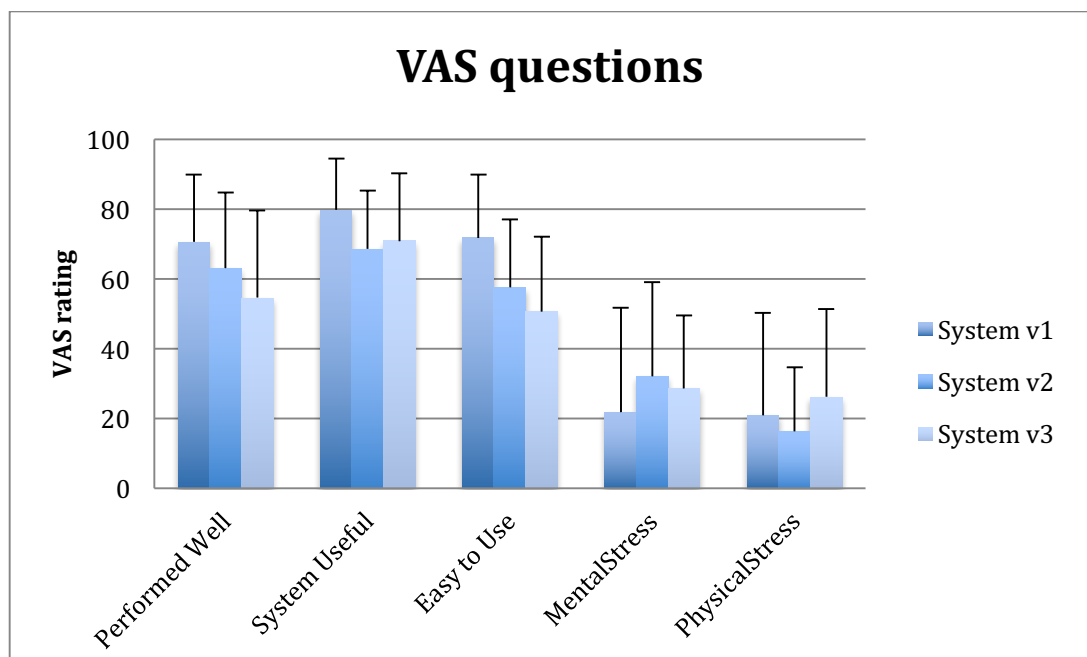
With the feedback from the students, we confirmed the feasibility of implementing the system, beginning with a prototype. If planned with a haptic/kinaesthetic option, it could be an add-on to the existing resources as one of the natural ways of learning anatomy.

4.2 STUDENT RATINGS OF LAHFS: VAS (QUANTITATIVE)

QUESTIONS

Participant ratings of their experiences with LAHFS on the five visual analogue scale (VAS) questions, compared across User Tests 1, 2, and 3 are summarized in Figure 3-1.

Figure 4-1 Comparison of VAS question across the system V1, 2 and 3

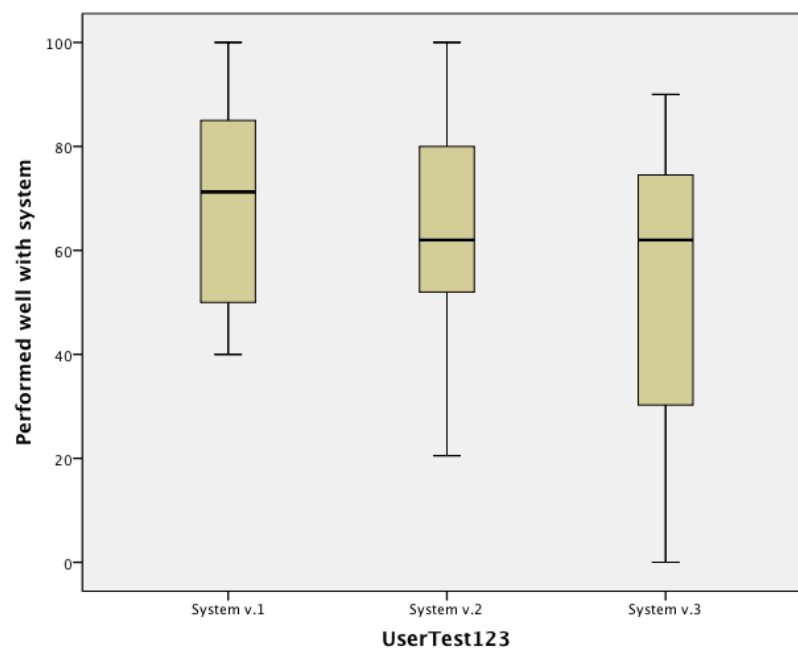


4.2.1 'Performed Well'

Across all three user tests, the rating of 'were you performing well with the system' was 60 ± 24 (66) (*mean \pm standard deviation (median)*) on the 0-100 point VAS, with 0 = very poor to 100 = very well. There was a non-significant decrease in this rating from 71 ± 19 (71) to 63 ± 22 (62) to 55 ± 25 (62) from Systems version 1 to version 2 to version 3 respectively (Figure 4-2), Kruskal-Wallis one-way between groups analysis of variance (ANOVA), $H=5.328$, $df=2$, $N=86$, $p=0.07$.

The Shapiro-Wilk tests for normality included $p=0.008$ for system version 3, so non-parametric ANOVA was used.

Figure 4-2 Performed Well with the System

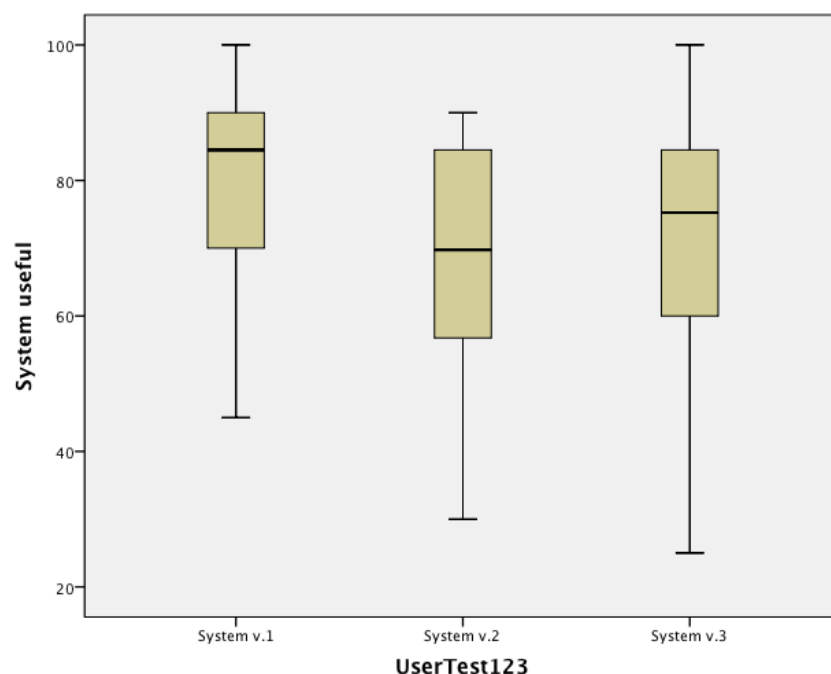


4.2.2 'System Useful'

The rating of 'was the system (or given interface) useful' across all three user tests was 72 ± 18 (76) on the 0-100 point VAS with 0 = totally useless to 100 = very useful. There was a decrease in the rating from 80 ± 15 (85) for version 1 to 69 ± 17 (70) for version 2 and a small increase to 71 ± 19 (75) for version 3 (Figure 4-3); these differences were not statistically different by Kruskal-Wallis ANOVA $H=5.504$, $df=2$, $N=86$, $p=0.064$.

The Shapiro-Wilk tests for normality included $p=0.026$ and $p=0.010$ for versions 1 and 3, respectively, so non-parametric ANOVA was used.

Figure 4-3 System Useful

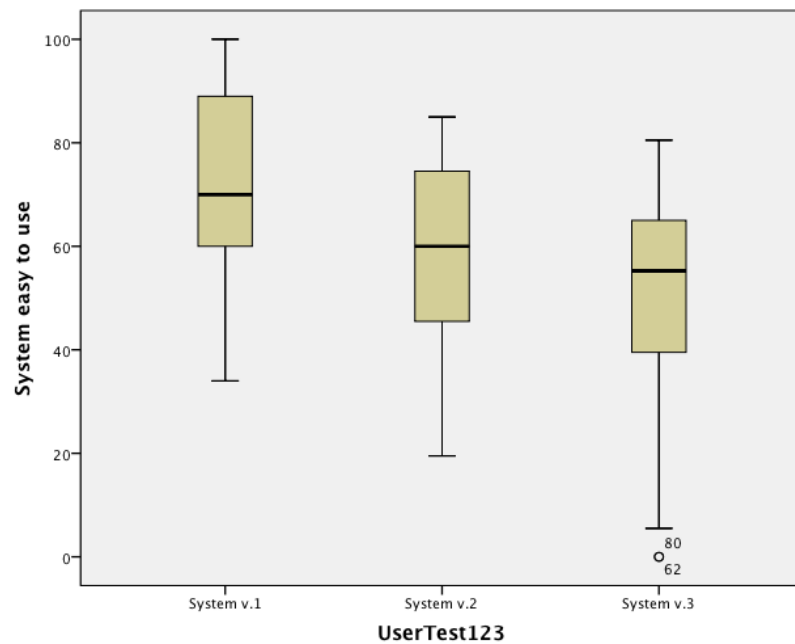


4.2.3 'Easy to use'

The rating of 'was it easy to perform the given task with the given interface' (user tests 1 and 2) or 'was it easy to use the system to explore the anatomical region' (user test 3) across all three user tests was 57 ± 22 (60) on the 0-100 point VAS with 0 = very difficult to 100 = very easy. There was a statistically significant decrease in this rating from 72 ± 19 (70) to 58 ± 20 (60) to 51 ± 21 (55) from Systems version 1 to version 2 to version 3, respectively (Figure 4-4), Kruskal-Wallis one-way ANOVA, $H=12.583$, $df=2$, $N=87$, $p=0.002$. Mean values for versions 1, 2, and 3 were 61.7, 44.3, and 36.6 respectively. Non-parametric post-hoc comparisons were significant for version 1 vs. 2 ($p=0.026$) and 1 vs. 3 ($p<0.001$), but not 2 vs. 3 ($p=0.227$).

The Shapiro-Wilk tests for normality included $p=0.006$ for version 3, so non-parametric ANOVA was used.

Figure 4-4 Easy to Use the System



4.2.4 'Mentally/physically stressed'

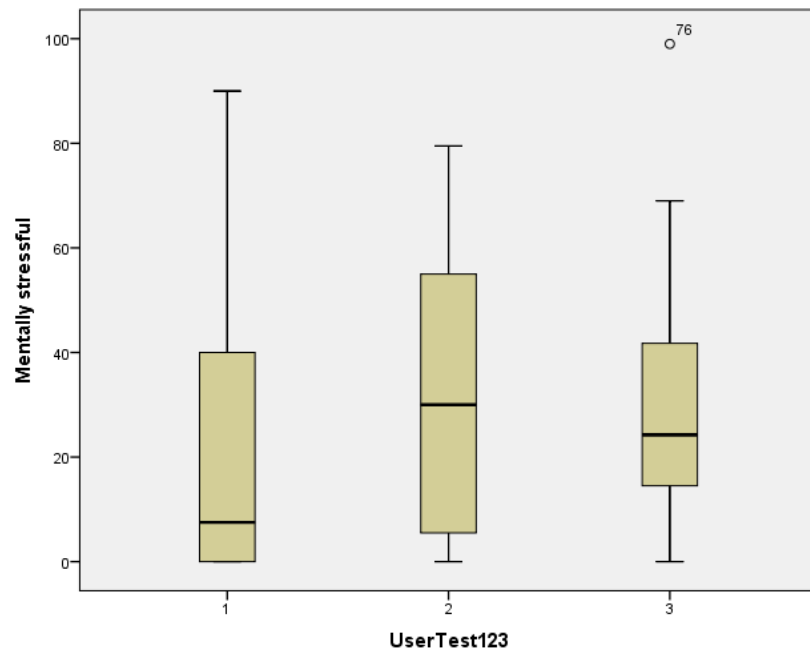
Across all three user tests, the ratings of 'did you get mentally stressed while using the system' and 'did you get physically stressed while using the system' were both generally low, 28 ± 25 (21) and 22 ± 24 (14) respectively, on the 0-100 point VAS, with 0 = not at all to 100 = very stressed.

Ratings of 'mentally stressed' non-significantly increased from system version 1, 22 ± 30 (8), to system version 2 and 3, 32 ± 27 (30) and 29 ± 21 (24) respectively (Figure 4-5), Kruskal-Wallis one-way ANOVA, $H=3.931$, $df=2$, $N=87$, $p=0.14$. Mean values for versions 1, 2, and 3 were 33.6, 47.4, and 46.3 respectively.

Chapter 4

Shapiro-Wilk tests for normality yielded $p < 0.001$, $p = 0.010$, and $p = 0.007$ for versions 1, 2, and 3 respectively, so non-parametric ANOVA was used.

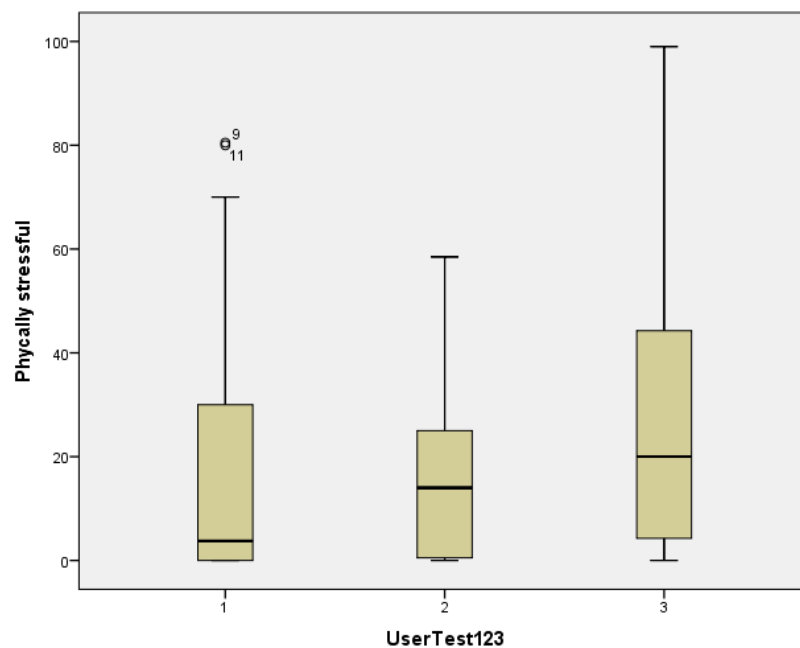
Figure 4-5 'Mentally Stressed'



Ratings of 'physically stressed' non-significantly increased from system version 1 to 2 to 3, 21 ± 29 (4), 16 ± 18 (14), and 26 ± 25 (20) respectively (Figure 4-6), Kruskal-Wallis one-way ANOVA, $H=3.837$, $df=2$, $N=87$, $p=0.147$. Mean values for versions 1, 2, and 3 were 37.7, 39.4, and 49.2 respectively.

Shapiro-Wilk tests for normality yielded $p \leq 0.001$ for all three versions, so non-parametric ANOVA was used.

Figure 4-6 'Physically Stressed'



4.2.5 Correlations amongst VAS question ratings

Correlations (Pearson's r) between each of the above five VAS questions were performed across all three user tests (Table 4-1).

Table 4-1 Correlations (r) between VAS questions.

	System useful	System easy to use	Mentally stressful	Physically stressful
Performed well	0.473 ^a	0.596 ^a	-0.360 ^a	-0.291 ^b
System useful		0.541 ^a	-0.147	-0.130
System easy to use			-0.293 ^b	-0.208
Mentally stressful				0.648 ^a

^a $p \leq 0.001$, ^b $p \leq 0.01$

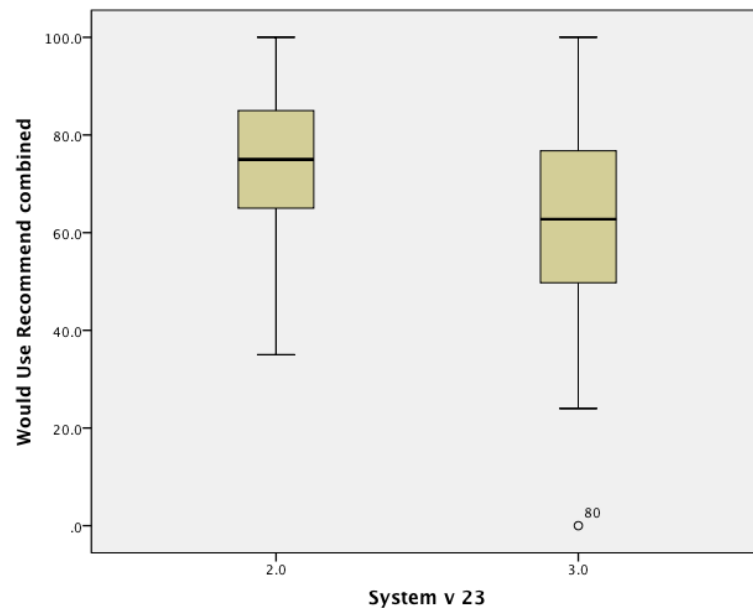
'Performed well', 'system useful', and 'system easy to use' strongly positively correlated with each other, as did 'mentally stressful' with 'physically stressful'. In contrast, there were weak or non-significant negative correlations between the two 'stressful' variables on the one hand and the other three VAS questions, 'performed well', 'system easy to use', and 'system useful'.

4.2.6 'Would use/recommend the system'

To address predicted usage, two different but related questions were asked: 'Would you use this system as an aid to learning when it is fully developed?' in version 2, 74 ± 17 (75), on the 0-100 point VAS with 0 = not at all and 100 = very likely; and 'Would you recommend the University use a system based on this one?' in version 3, 59 ± 21 (63), on the 0-100 point VAS, with 0 = not at all to 100 = strongly recommend.

These data were approximately normally distributed, so a t-test was used to compare responses to these two questions, which was significant: $t=2.876$ ($df=63$), $p=0.005$.

Figure 4-7 'would use' in V2 and 'would recommend' in V3



4.2.6.1 Intention to use the system

Users of version 2 indicated that they were likely to use the system when fully developed, 74 ± 17 (75); and users of version 3 that they would recommend that the university use a system based on the present version, 59 ± 21 (63); neither question was included in user test 1. Although these two questions are different, both are related to intention to use the system. Standard multiple regression of these questions against the 5 VAS questions above yielded an overall strong positive correlation, $r=0.652$, adjusted $r^2=0.374$, $F=8.296$, $p<0.001$. Zero-order and part-correlations are shown in Table 4-2, with 'system useful' significantly positively correlated with 'would use/recommend'.

Table 4-2 Standard multiple regression: Would recommend, with VAS5 and Quiz useful (UT3)

Questions	zero-order correlation	Part correlation	p value
Performed well with system	0.486	0.139	.206
System useful	0.575	0.016	.881
System easy to use	0.468	0.195	.078
Mentally stressful	-0.054	-0.053	.627
Physically stressful	0.032	0.152	.167
Quiz useful	0.661	0.342	.003

Table 4-3 Correlations of intention to use the system with other VAS questions

Question	Zero-order correlation	Part correlation	p value
Performed well	0.477	0.174	0.092
System useful	0.569	0.285	0.007
System easy to use	0.517	0.181	0.079
Mentally stressful	-0.097	0.056	0.583
Physically stressful	-0.036	0.095	0.353

4.2.7 'Quiz useful' and scores on quiz

The third version of the system included a quiz, and the question 'was the quiz useful as a check on understanding?' yielded a very positive response, 77 ± 18 (80), on the 0-100 point VAS, with 0 = not at all to 100 = very useful.

Chapter 4

Participants generally did well on the quiz, with average scores of 7.1 ± 2.6 (8) out of 10.

There was a moderate positive correlation between participants' score on the quiz and their rating of its usefulness, Pearson's $r=0.443$, $r^2=19.6\%$, $n=43$, $p=0.003$.

With the introduction of the quiz in system version 3, it was possible that participants' response to 'were you performing well with the system?' may have been influenced by their performance on the quiz i.e. perhaps participants interpreted the question as relating to how they felt they did on the quiz, in addition to their performance with LAHFS. To check this, a Pearson correlation coefficient was computed between the quiz result and "performed well with system", which yielded a small positive correlation, $r=0.350$, $r^2=12.3\%$, $n=43$, $p=0.021$.

Table 4-4 Correlations (Pearson's r) between VAS questions across versions 1,2, and 3.

	Quiz useful	Quiz result	Weighted Quiz result
Would use or recommend	0.661 ^a	0.526 ^a	0.457 ^b
Quiz useful		0.443 ^b	0.401 ^b
Quiz result			0.977 ^a

^a $p \leq 0.001$, ^b $p \leq 0.01$

4.2.8 Summary of findings on VAS questions

As the system developed from version 1, with only two organs (lungs and liver), to versions 2 and 3, with large numbers of blood vessels and the heart chambers labelled, the ease of using this system decreased.

The first three VAS questions (Perform Well, System Useful and Easy to Use) showed two common features:

- All were rated highly by students, with means in the range 50-80%.
- All showed a rating decline from version 1 to version 3, except a non-significant very small increase between versions 2 and 3 for System Useful.

The decline in Easy to Use and Perform Well from versions 1 to 3 correlated with increasing system complexity, including more structures present and labelled, and the addition of a quiz.

Across the three versions of LAHFS, students' ratings on these three VAS questions (Performed well, System useful, System easy to use) were strongly positively correlated (Table 4-3).

The last two common VAS questions (MentalStress and PhysicalStress) indicated that students were generally not stressed by the system, with means in the range of 16-32% across the three versions.

The quiz in version 3 was rated highly on a VAS scale by the students (mean 77), and students generally did well on the quiz (mean 7.1, median 8, out of 10).

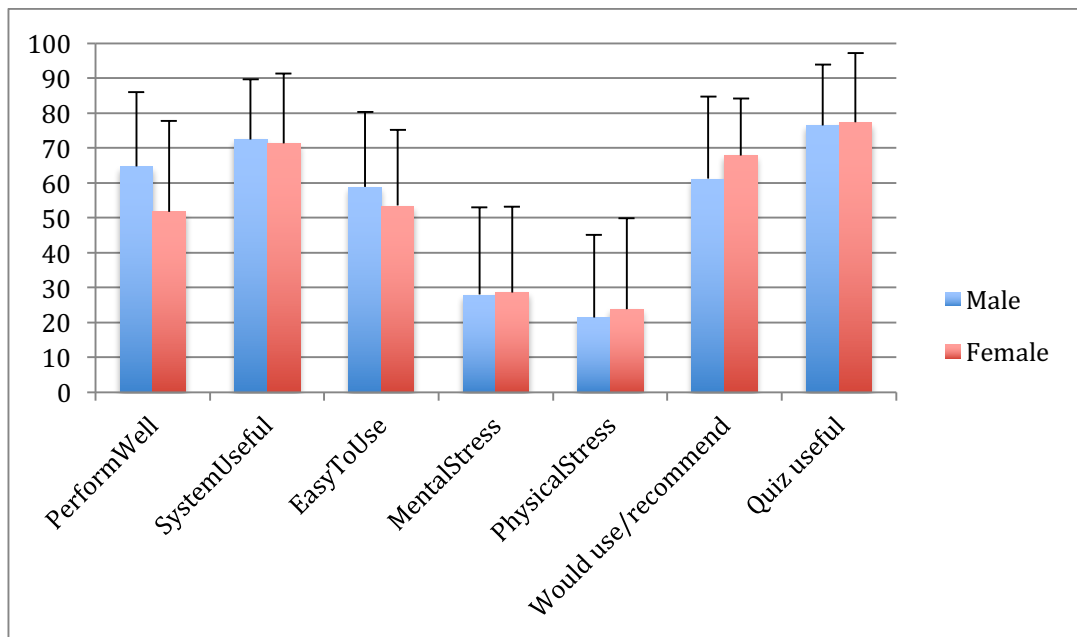
4.3 GENDER, COURSE/UNIT OF STUDY, AND PRIOR EXPERIENCE WITH HAPTIC OR 3D INTERFACES

Participants' ratings of their experiences with LAHFS were compared by gender, course or unit of study, and prior experiences with haptic or 3D interfaces, to determine if any of these variables affected ratings of LAHFS.

4.3.1 Gender

Figure 4-8 summarises responses by gender to the 5 VAS questions across UT1, 2 and 3, 'would you use/recommend the system' (only asked in UT2 and 3), and 'quiz useful' (only in UT3).

Figure 4-8 Gender comparisons



The only statistically significant difference between genders on the five VAS questions (performed well, system useful, easy to use, mentally and physically stressed) was 'performed well', with females rating their performance lower than males, 52 ± 26 (55) vs 65 ± 21 (70), respectively, t -test $p=0.017$. Despite this, females more strongly recommended the system to university (UT3) or indicated they were more likely to use the system (UT2) than males, 68 ± 16 (70) vs 61 ± 24 (60), t -test $p=0.037$.

Quiz scores (out of 10) did not differ by gender, males 6.9 ± 2.4 (8) vs females 7.4 ± 2.8 (8), Mann-Whitney U $p=0.389$.

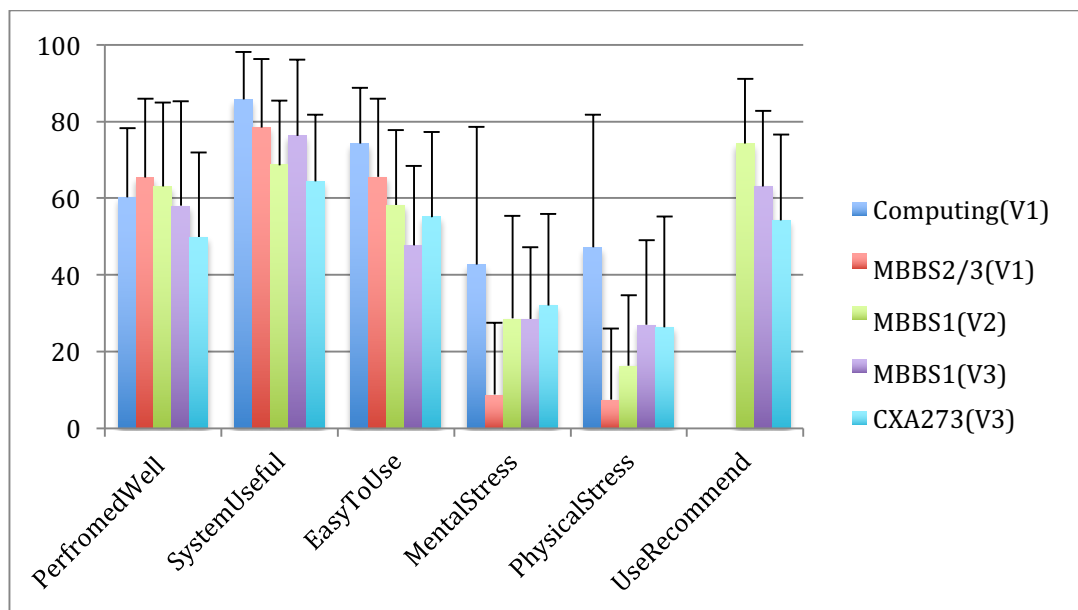
4.3.2 Course/unit of study

Three pair-wise comparisons were of particular interest:

Were there differences between students in two different courses testing the same version of the system?

1. Within version 1, computing students vs Year 2 or 3 medical students.
2. Within version 3, Year 1 medical students vs allied health sciences and education students enrolled in CXA273.
3. Version 2 vs version 3, Year 1 medical students.

Figure 4-9 Responses on VAS questions from five different cohorts across three system versions.



4.3.2.1 Computing vs Year 2/3 Medical Students with system version 1

There were no significant differences between Computing ($n=10$) and medical students ($n=8$) in user test 1 on any of the 5 VAS questions, with p -values ranging from 0.131 to 0.573.

4.3.2.2 Year 1 Medical Students vs Health sciences and Education

students enrolled in CXA273 with system version 3

Statistically significant differences between Year 1 medical students ($n=24$) and CXA273 ($n=20$) students on their ratings of system version 3 were found for 'System useful' and 'Quiz useful', with year 1 medical students rating usefulness higher than CXA273 students (Figure 4-10 and Figure 4-11). In addition, year 1 medical students scored higher than CXA273 students on the quiz (Figure 4-12).

- System useful: MBBS1 76 ± 20 (83), CXA273 64 ± 17 (70), Mann-Whitney U test, $p=0.013$.
- Quiz useful: MBBS1 83 ± 15 (85), CXA273 70 ± 20 (75), Mann-Whitney U test, $p=0.012$.
- Quiz result: MBBS1 7.8 ± 2.3 (8), CXA273 6.3 ± 2.6 (6.5), Mann-Whitney U test, $p=0.031$.

Figure 4-10 Rating on System Useful by MBBS1 and CXA273 in system V3

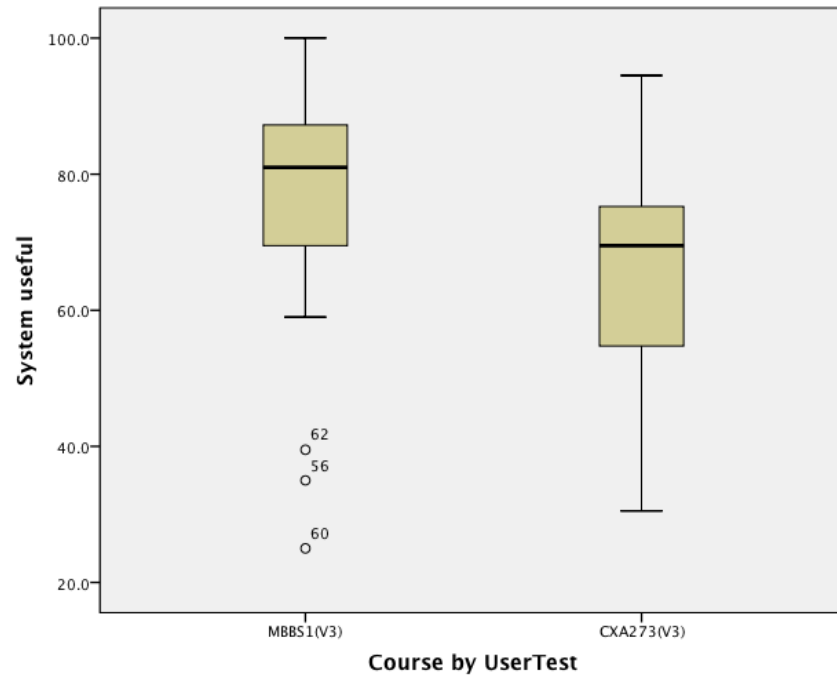


Figure 4-11 Rating on 'Quiz useful' by MBBS1 and CXA273 students in system V3

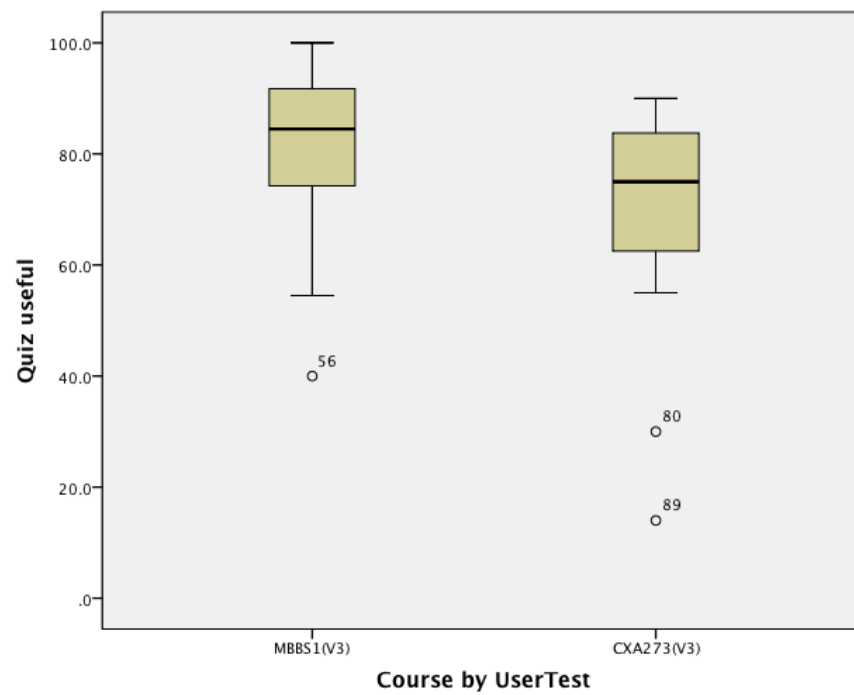
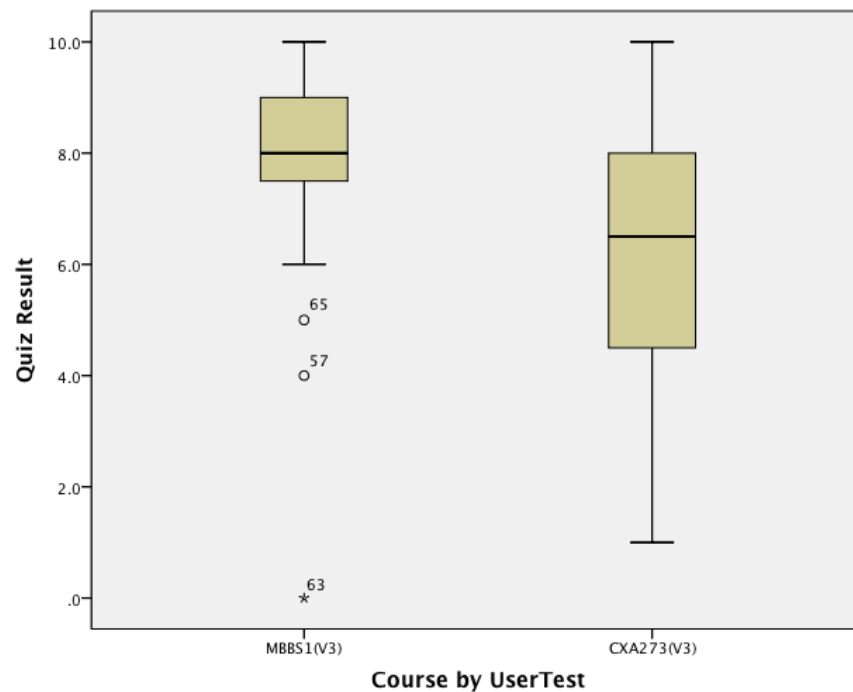


Figure 4-12 Quiz results by MBBS1 and CXA273 students in system version 3



4.3.2.3 Year 1 Medical Students with system versions 2 vs 3

Different cohorts of year 1 medical students tested system version 2 ($n=25$) and system version 3 ($n=24$). The only statistically significant difference was between the related questions 'would you use the system' (system version 2), 74 ± 17 (75), and 'would you recommend to the university' (system version 3), 63 ± 20 (65), t -test, $p=0.049$.

Some notable trends that did not reach statistical significance included the following:

- 'System useful' increased from V2 to V3, 69 ± 17 (70) and 76 ± 20 (83), respectively, Mann-Whitney U test, $p=0.056$.
- 'Easy to use' decreased from V2 to V3, 58 ± 20 (60) and 48 ± 21

(50), respectively, t-test, $p=0.092$.

- 'Physically stressed' increased from V2 to V3, 16 ± 18 (14) and 27 ± 22 (25), respectively, Mann-Whitney U test, $p=0.057$.

In summary, there were no differences between the ratings of system version 1 by year 2 or 3 medical students and computing students. In system version 3, year 1 medical students rated the system and quiz more useful than allied health sciences and education students enrolled in CXA273. Thus, differences between system versions reported in section 4.2 are probably not strongly influenced by which course students are enrolled in, except for 'system useful', where the trend for improvement between system V2 to V3 rated by year 1 medical students was masked by the lower ratings of health sciences and education students enrolled in CXA273.

4.3.3 Previous experience with haptic or 3D systems

To determine if prior experience with haptic or 3D interfaces influenced participants' ratings of the LAHFS system, questions were included on the survey instruments. Due to relatively small participant numbers in each user test, data are presented for all three user tests combined for the VAS questions, except for those questions that were only included on later user tests: the 'Would use / recommend the system' questions were

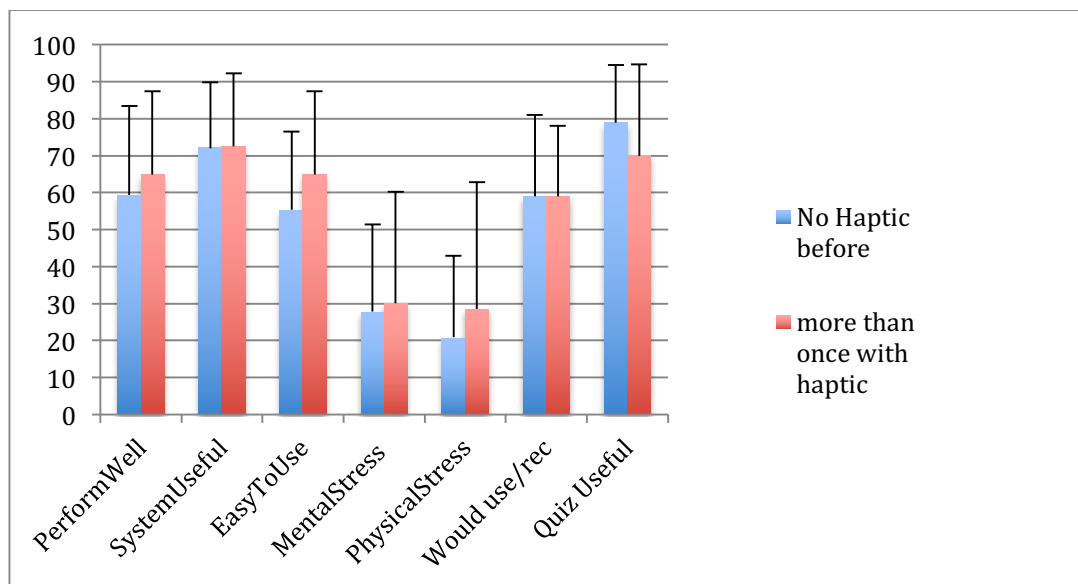
Chapter 4

included only in System v2 and v3, and the 'quiz useful' question was only in System v3.

4.3.3.1 Previous experiences with Haptic

Participants were asked if they had prior experiences with any form of haptic device, with options 'not at all', 'not more than 10 times' and 'more than 10 times'; the responses were $n=74$, 11, and 4 respectively. For analysis, the responses were reduced to two categories of prior experience: 'None' ($n=74$) and 'More than once' ($n=15$).

Figure 4-13 Users' ratings of the system with different prior experience levels with Haptic



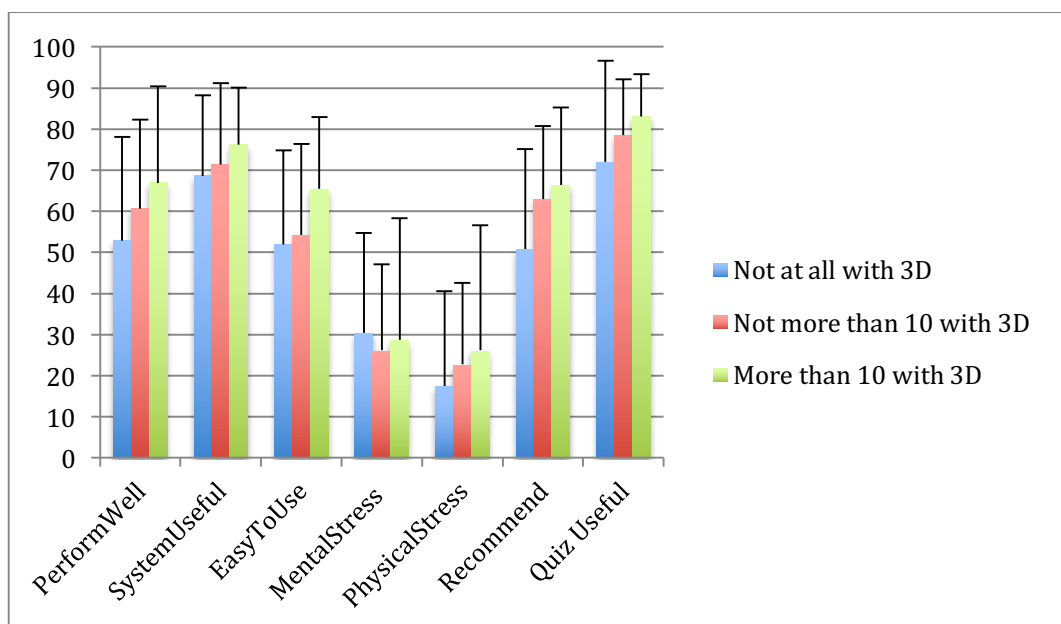
Chapter 4

There were no significant differences in ratings on any of the VAS questions, nor did quiz results differ between participants with and without prior haptic experience (Figure 4-13). An interesting trend was that the system was rated easier to use by those with prior experience with haptic systems, 65 ± 22 (64), compared to those with no prior experience, 55 ± 21 (60), but this did not reach statistical significance, Mann-Whitney U test, $p=0.138$.

4.3.3.2 Previous experiences with 3D interfaces

Similar numbers of participants had no, some, or considerable previous experience with 3D interfaces: not at all ($n=26$), not more than 10 ($n=35$), and more than 10 ($n=28$), enabling comparisons of these three response categories across all system versions combined (Figure 4 – 14).

Figure 4-14 Users' assessment on the system with different experience levels with 3D



Although there were trends for participants with greater prior experience with 3D interfaces to rate LAHFS and their performance with it higher, but also their physical stress higher, only 'easy to use' was statistically significant, by ANOVA, $p=0.045$, but Gabriel post-hoc pair-wise comparisons indicated no differences between the categories of none, 1-10, and more than 10 prior experiences.

'Performed well', 'system useful', 'mentally stressful', 'physically stressful', and 'quiz useful', all were not significantly different by Kruskal-Wallis ANOVA, $p=0.081$, 0.297 , 0.868 , 0.468 , and 0.594 , respectively. 'Would use' (version 2) or 'would recommend to university' (version 3) did not differ by ANOVA, $p=0.072$.

Version 3 included a formative quiz to provide participants the opportunity to rehearse their knowledge through identifying anatomical structures. Scores on the quiz (5.9 ± 3.0 (6), 7.8 ± 2.3 (8), and 7.7 ± 1.5 (8), for none, not more than 10, and more than 10 prior experiences, respectively) were not significantly different by Kruskal-Wallis ANOVA, $p=0.134$.

If we look at the results by grouping them into two, experience and no experience, as for the haptic question, prior experience may improve user

acceptance, as well as performance on the quiz. The result was just significantly higher in those with prior experiences than those without, 7.8 ± 2.1 vs 5.9 ± 3.0 , respectively, $p=0.050$.

The usefulness of this quiz was rated highly by participants, 77 ± 18 (80). Participants generally did well on the quiz, $71\% \pm 26$ (80%). There were moderate positive correlations between quiz score with rating of usefulness of the quiz, $r=0.443$ ($p=0.003$), and between quiz score with rating of performance with the system, $r=0.350$ ($p=0.021$).

4.4 ANALYSIS OF LEARNING STYLE WITH SYSTEM V3

In order to see if participants' learning styles, as assessed by the VARK questionnaire, have any influence on their ratings of the LAHFS system, system version 3 participants' responses were correlated to the VAS questions and their quiz results with their scores on the VARK questionnaire.

The percentage of visual (V), aural (A), read/write (R), and kinaesthetic (K) options chosen out of the total number of options selected was used due to a relatively small population of the study. The percentage of different options by each participant were V $23\% \pm 10$ (24%), A $25\% \pm 12$ (24%), R

Chapter 4

22% \pm 9 (21%), and K 29% \pm 13 (28%), with all approximately normally distributed amongst $n=43$ system v3 participants who completed the VARK questionnaire (Shapiro-Wilk tests of normality $p=0.078$ to 0.288). These percentages are similar to those reported on the VARK website, based on 74,932 respondents from January to March 2015: V 21.7%, A 24.6%, R 24.9%, and K 28.8%; as well as for those in medical fields (13,181 respondents): V 22.0%, A 24.3%, R 24.9%, and K 28.8% (VARK Learn Limited, 2016).

The Pearson's correlations (r) of percentage V, A, R, and K with the 5 VAS questions are shown in Table 4-5. None of these correlations were statistically significant. Interestingly, only 'kinaesthetic' positively correlated with performed well ($p=0.135$) and easy to use ($p=0.418$), but also with mentally stressed ($p=0.468$) and physically stressed ($p=0.339$).

Table 4-5 Correlations (Pearson's r) between VARK learning style percentages and VAS questions.

	Performed well	System useful	Easy to use	Mentally stressed	Physically stressed
V %	-0.005	0.131	-0.021	-0.098	-0.041
A %	-0.151	-0.173	-0.115	-0.008	-0.111
R %	-0.123	0.037	-0.005	-0.039	-0.024
K %	0.232	0.027	0.127	0.114	0.149

Correlations $r>0.1$ are highlighted in green and $r<-0.1$ in orange.

Similarly, there were weak positive but non-significant correlations of 'kinaesthetic' with 'would recommend to university', 'quiz useful', and

Chapter 4

quiz results ($p=0.413$, 0.290 , and 0.217 , respectively). ‘Visual’ learners also weakly but non-significantly positively correlated with finding the ‘system useful’ and ‘quiz useful’ ($p=0.403$ and 0.214 , respectively).

Table 4-6 Correlations (Pearson’s r) between VARK learning style percentages and VAS questions as well as quiz results.

	Would Recommend	Quiz useful	Quiz result
V %	0.018	0.197	-0.107
A %	-0.163	-0.272	-0.103
R %	0.010	-0.100	-0.015
K %	0.128	0.165	0.194

Correlations $r>0.1$ are highlighted in green and $r<-0.1$ in orange.

4.4.1 Summary of learning styles with LAHFS

VARK learning styles do not strongly affect the acceptance of the LAHFS system. However, there were weak positive correlations of kinaesthetic learning style percentage with ratings of LAHFS, but these did not reach statistical significance.

4.5 ANALYSIS OF VARIOUS LEARNING ACTIVITIES AND RESOURCES

Participants who tested version 3 were asked to rank a variety of learning resources and activities including LAHFS on their usefulness, from 1 (most

Chapter 4

useful) to 8 (least useful). The percentage of students ranking each 1st, 2nd, etc., is shown in Figure 4 - 15, and mean \pm standard deviation (median) ranks were as follows (Table 4-7):

Table 4-7 Mean and median rankings of eight learning resources

Learning resources	Mean \pm SD (median)
Lectures, tutorials, and practicals (face-to-face sessions)	2.1 \pm 1.6 (1)
Lectures, tutorials, and practicals (notes)	2.9 \pm 1.6 (3)
Textbooks	3.0 \pm 1.6 (3)
Haptic system (LAHFS)	4.8 \pm 1.8 (5)
Atlases	5.1 \pm 2.0 (5)
Software	5.5 \pm 2.1 (5)
Websites	6.2 \pm 1.9 (7)
Other	7.5 \pm 1.6 (8)

Friedman's two-way analysis of variance (ANOVA) by ranks was used to compare the ranking, which revealed that there were significant differences in rankings: $X^2(7)=105.578$ $p<0.001$. Wilcoxon signed ranks tests were used for post-hoc pair-wise comparisons of LAHFS with each other learning resource.

The LAHFS system was ranked significantly higher than websites, $p=0.009$, and 'other' resources, $p=0.001$. 'Other' resources listed by respondents were Peer Assisted Study Sessions (PASS), learning with friends, past exam questions, and online learning games. PASS is the group study sessions led

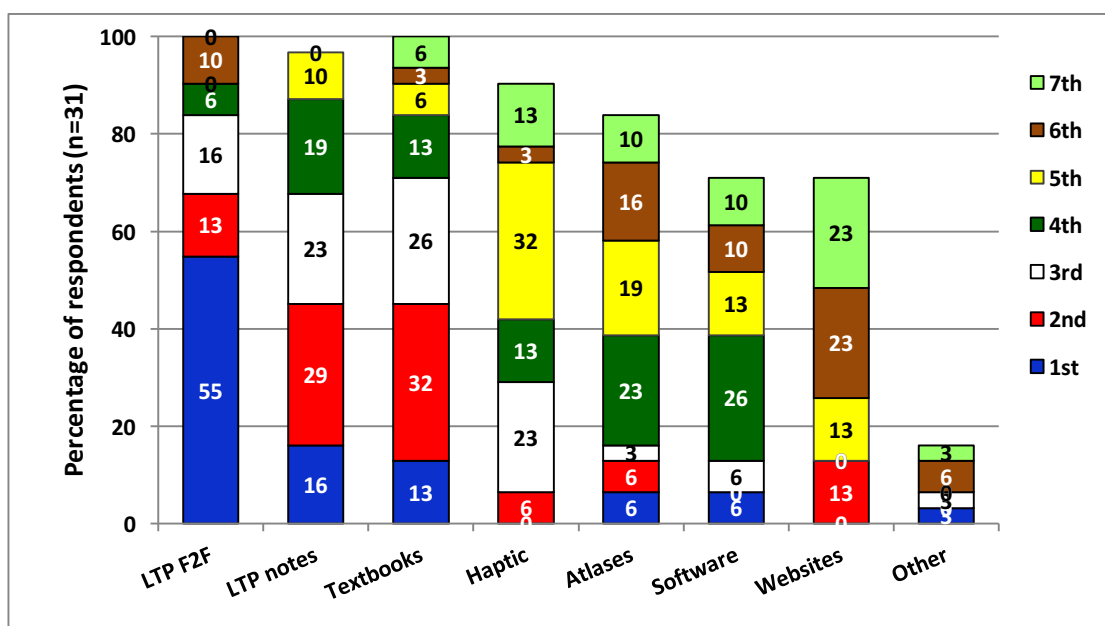
Chapter 4

by near-peers (students who have previously succeeded in the unit of study). PASS is an internationally accredited program offered at over 1500 universities worldwide, including selected year 1 units at the University of Tasmania.

There were no significant differences between the rankings of LAHFS and software, $p=0.195$, and anatomy atlases, $p=0.412$. Programs are named by the respondents included Anatomy & Physiology Revealed, Interactive Physiology, and Muscle Pro 3 app.

The LAHFS system was ranked significantly lower than lecture, tutorial and practical face-to-face sessions; notes from lecture, tutorial and practical sessions; and textbooks; all $p=0.001$.

Figure 4-15 Preferred types of resources of learning anatomy



In summary, LAHFS, used by the participants only once for 10-15 minutes, ranked lower than face-to-face lecture, tutorial, or practical sessions, notes from these sessions, and textbooks as preferred learning resources. Notably, LAHFS ranked on par with other learning resources including atlases and software, and higher than websites and 'other' resources.

4.6 ANALYSIS OF QUALITATIVE QUESTIONS

4.6.1 Qualitative Data Analysis - Thematic Analysis

For the qualitative data analysis, we used Thematic Analysis to focus on identifying patterned meaning across a collected qualitative data set.

The two main open ended questions asked in the survey will be the focus of the section and they are:

- What was the best aspect of the system?
- What suggestions do you have for improvement?

4.6.2 Best aspects

Three main keywords, interactive, haptic, and 3D were counted from the free form comments from questionnaire. The 'haptic' keyword includes mentioning other related keywords such as density, pressure, tactile, feel, depth, tenderness of organ, and touch. The '3D' keyword includes rotate, space, and moving (Table 4-8).

The total of eleven (11) occurrences of 'interactive' features, twenty-three (23) of the 'haptic' keywords, and nineteen (19) of '3D' were mentioned by respondents as the best aspects of the system.

Table 4-8 Qualitative Comments

	Best aspect	Improvement
Interactive feature	"The ability to interact and move the structures, as well as learn their names." "Interactive set up" "Interactive. Good for kinaesthetic learners"	Summary of the researcher from the comments: 29 out of 40 comments indicated the haptic interface required improvement.
Haptic feedback	"The haptic feedback makes the system more interactive"* "The depth that could be determined for each organ. Also the pressure that was felt when pushing in." "Being an interactive when you should touch and see the different parts of the system" "The ability to feel how hard the surface of structures was. Good 3D images gives you a good perspective" "You could feel the difference in texture of organs." "touching"	"I found it hard to use the pen (maybe it moved too quickly)" "Hard to pin point the smaller structures"
3D	"The 3D-feel of the system/sense of space it gave." "Being able to rotate the organs" "visual	

Chapter 4

presentation	3D model of the anatomical feature"	"Getting used to the control of the pen was hard but would come with practices."
Overall comment	"Good way to learn." "Good concept." "It's not boring like a lot of study and also gives detail on where different vessels are in regards to one another." "It gives a different approach of learning." "The system gave a visual diagram of the anatomy and I was able to pick pieces around to see all sides of it."	Other suggestions included 3Dscreen (one response) or 3D glasses, improved graphics, and a voice talking through.
Others	fun (1), enjoyable (1), interesting (1), image (2), colours (1), labels (1), quiz (3)	

(*this one was counted to the 'interactive' item as well as the 'haptic' item.)

4.6.3 Suggestions for improvement

40 out of 44 people left a comment in this section.

29 responses out of 40 related to difficulty using the interface and the haptic device as requiring improvement.

4.7 SUMMARY OF CHAPTER 4

What we have found out from the initial survey was that 3D version with interaction such as zooming and rotation would be useful additions to the current resources. The LAHFS system was implemented in a cyclic manner with different user tests were done accordingly. The results from the collected responses from users with three different versions of LAHFS were analysed in this chapter.

Chapter 4

Different versions were used to collect information on how they performed, if the system was useful, was easy to use, mentally or physically stressed while using the system, and if they would use it or recommend it to the university. Gender difference, major difference, and prior experience difference were another elements used to analyse. Also correlations between VAS questions, with intention to use the system, between preferred learning styles along with their study were calculated. Quiz results between different courses of study (MBBS1 and CXA273), users' ratings of the system with different experience level with haptic and 3D were additionally analysed.

(RQ1): What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy?

(RQ2): What user characteristics influence his/her learning from and acceptance of the haptic learning system?

(RQ3): What elements of the haptic learning system influence user acceptance?

CHAPTER 5 DISCUSSION

5.1 RESEARCH QUESTIONS AND DISCUSSION

Although anatomy knowledge is essential in the biological and health sciences, there are many challenges for students in learning anatomy. The 3-dimensional complexity of human anatomy is inadequately captured in 2-dimensional representations, such as textbooks or atlas diagrams, or 2-dimensional sections through the body, such as from radiological images including computed tomography (CT) and magnetic resonance imaging (MRI). Resources that include 3-dimensional representations include anatomical models (plastic or other materials) and real human bodies (cadavers), which may be dissected by students of anatomy, or students may inspect prosected cadavers. Use of cadavers has ethical, resourcing, and cost issues (Adams, Bertram, & McMenemy, 2015; Shaikh, 2015).

Anatomy, as an important subject in medical and health sciences, uses various resources to assist learning (Figure 4-15). It is evident that multi-sensory experiences are more realistic in learning anatomy (Newell & Mitchell, 2015; Vanags et al., 2012). Adding haptic feedback to a virtual anatomy computer system provides another sensory dimension to learning the subject.

From the initial survey that was conducted (Yeom, 2011), it was clear that medical students in the local context of the University of Tasmania wanted an additional system/resource to assist learning anatomy. Additionally, there were few studies investigating the use of haptic feedback in the context of undergraduate student learning of anatomy. Therefore, three different versions of LAHFS were developed, and each implemented in a user test, to address the Research Questions (Chap 2, p39). At each user test, undergraduate university students tried LAHFS. The first user test was held in a separate classroom with the system installed in the School of Medicine and the School of Computing over several occasions. It was difficult to attract participants, with only 8 medical students testing version 1 (3.5% response rate from 230 year 2 and 3 medical students invited). Environmental settings for the user tests 2 and 3 were more natural and authentic: teaching laboratories (Figure 3-7) during a regularly scheduled anatomy practical learning session.

Versions 2 and 3 were tested by a larger number of students, all of whom were studying anatomy, with response rates in the range of 20-31%.

Each participant was asked to complete a survey (Appendix 2), which included demographic information (age and gender), course of enrolled study, and prior experience with 3D or haptic interfaces. The survey also included several questions with VAS response scales, to determine the extent to which participants felt they were performing well with the system, if the system was useful, was easy to use and whether they were mentally or physically stressed.

These VAS questions enabled research question 1 (RQ1) to be addressed: What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy? The collected demographic information from the survey, combined with VAS questions and quiz performance, enabled research question 2 (RQ2) to be addressed: What user characteristics influence his/her learning from and acceptance of the haptic learning system?

In user test 2 and 3, an additional VAS question asked if they would use or recommend the University to use the system. In user test 3, another VAS question asked if they found the quiz useful. Open-response questions sought participants' opinions of the best aspects of the system, and those

in need of improvements, including suggestions for improvement. Additionally, user test 3 included the VARK questionnaire (Appendix 2) to assess participants' preferred learning style(s). These and the other questions on the survey, as well as the characteristics of the three different versions of the LAHFS, enabled research question 3 (RQ3) to be addressed: What elements of the haptic learning system influence user acceptance?

Because haptic feedback is interpreted by the brain through a combination of visual clues of deformation and tactile responses with vibration (Basdogan et al., 2004), the LAHFS used visual clues and different levels of force feedback for different organs. Surface texture was used to display the difference of organs such as depth and stiffness (hardness), of the various organs in the virtual anatomical model, including lungs, liver, and heart. In LAHFS, when the user touches an organ, the feedback illustrates visual deformation of the organ along with the haptic feedback. An experienced anatomy lecturer tested the LAHFS and confirmed that the LAHFS feedback was similar to interacting with embalmed cadaveric liver, heart or lungs.

Constructivism learning theory suggests active experience with the materials helps build knowledge (Huang, Rauch, & Liaw, 2010).

The design of LAHFS as well as the quiz at the end of user test session were based on multimedia design principles and cognitive load theory (Ayres, 2015; Paas, Renki, & Sweller, 2013)

Participants generally thought the haptic learning system was useful, was easy to use, and that they had performed well with it. Their perception of any negative aspects was low, with little experience of mental or physical stress. Results for each research question are presented in more detail and discussed in the following subsections.

5.2 RESEARCH QUESTION 1

RQ1. What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy?

The mean responses to if they performed well with the system, if it was useful, easy to use, if they would use the system or recommend it to the university, and if the quiz was useful, were positive. Mental and physical stresses when using the system were low. However, there were wide ranges of responses to the questions amongst participants, and some differences across the three versions.

5.2.1 Discussion on results from the VAS questions

As the system developed through versions 1 to 3, the content was expanded from 1 to 3 modules (Table 3-2), and the complexity of the system increased with a greater number of anatomical structures included and labelled. Smaller anatomical structures, e.g. blood vessels, were included in versions 2 and 3. It was more difficult to give haptic feedback through this device on these smaller structures. In this section, we will look at how the users responded to each question on the questionnaire.

‘Performed Well’: The responses when the users were asked if they performed well with the system (Figure 4-2) decreased from version 1 to version 3, but these differences were not statistically significant. With the introduction of the quiz in system version 3, it was possible that participants’ response to ‘were you performing well with the system?’ may have been influenced by their performance on the quiz, i.e. perhaps participants interpreted the question as relating to how they felt they did on the quiz, in addition to their performance with LAHFS. To check this, a Pearson correlation coefficient was computed between the quiz result and “performed well with system”, which yielded a small positive correlation, $r=0.350$, $r^2=12.3\%$, $n=43$, $p=0.021$, suggesting that this may have been the case.

‘Usefulness of the System’: The responses about whether the system was useful were rated as 72 ± 18 (76) across all the user tests. There was a decrease from version 1 to version 2 (Figure 4-3), however this decrease was not statistically significant. Year 1 medical students’ ratings increased from 69 ± 17 (70) to 76 ± 20 (83) (non-significantly, $p=0.056$) on this item from version 2 to version 3. Perhaps the addition of the quiz, for students to receive feedback on their learning, influenced this small improvement in its usefulness.

‘Easy to Use’: This was rated as 57 ± 22 (60) across all the user tests. It was the only item that decreased significantly (version 1 vs. 2 ($p=0.026$) and 1 vs. 3 ($p<0.001$)), from 72 ± 19 (70) to 58 ± 20 (60) to 51 ± 21 (55), versions 1,2, and 3 respectively (Figure 4-4). The system increased in complexity, with more and smaller anatomical objects including blood vessels, from version 1 to 3. Additionally, more functionality, and a submenu to move around among different modules and the quiz, were added (Table 3-2). This increasing complexity evidently resulted in a decrease in perceived ease of use as different studies reported (Burke, 2013; Young, Van Merriënboer, Durning, & Ten Cate, 2014).

Ease of use and the system’s usefulness had a moderate by positive relationship ($r=0.541$, $p \leq 0.001$), unlike in the Shroff et al. (2011) research

that showed ease of use had significant influence on perceived usefulness.

Most of the open-response comments from this study relating to improving the LAHFS system related to the need for improvement to the haptic interface (Table 4-8). Teklemariam and Das (2015) studied and confirmed the usability of haptic interaction with virtual objects in product design using Phantom Omni. The researchers believed a haptic feedback device such as Phantom Omni with virtual objects reduced the overall cost to achieve the outcome of design products. However the device could be more advanced in free hand interaction.

‘Mental and Physical Stress’: In response to the questions to discover if the users were mentally or physically stressed, the average assessments of three versions were 28 ± 25 (21) for mentally stressed (Figure 4-5) and 22 ± 24 (14) for physically stressed (Figure 4-6) out of 100. The Phantom Omni device was not used previously by the users, and virtual haptic feedback was a new experience for most participants. Despite the increasing complexity from versions 1 to 3, and the addition of the quiz to version 3, this did not result in an increase in mental or physical stress. This suggests that although many participants reported that the haptic device could be improved to increase its ease of use, nevertheless they were not particularly physically or mentally stressed by it. Furthermore,

the quiz in version 3 did not create additional stress on participants, which is unsurprising, given that it was formative.

Correlations among VAS questions: It was found that ‘performed well’, ‘system useful’, and ‘system easy to use’ were strongly positively correlated with each other. This was similar to the results of Hess (2014) and Shroff (2011), when they reported a reliability generalisation study based on the features of TAM. Also ‘mentally stressful’ with ‘physically stressful’ were strongly positively correlated. In contrast, there were weak or non-significant negative correlations between the two ‘stressful’ variables on the one hand and the other three VAS questions, ‘performed well’, ‘system easy to use’, and ‘system useful’ (Table 4-1).

User acceptance and intention to use the system:

Most of the Technology Acceptance Model (TAM) related research used two elements: ease of use and usefulness as predictors of intention to use the system (Davis et al., 1989; Lee & Lehto, 2013; Marangunić & Granić, 2015). The two questions, ‘Would you use this system as an aid to learning when it is fully developed?’ in version 2, and ‘Would you recommend the University use a system based on this one?’ in version 3, both relate to the intention to use the system and were rated positively, at 74 ± 17 (75) and 59 ± 21 (63) respectively. The TAM of Davis posits that usefulness and ease of use are the main determinants of user

acceptance and intention to use a system (Davis et al., 1989; Lee & Lehto, 2013; Marangunić & Granić, 2015). The behavioural intention to use (BI) by Turner and his team (2010) is interpreted as acceptance in this study. Would use it or Recommend it to university however the original both elements are still valid to measure acceptance of technology.

A strong positive correlation between 'system useful' and 'would use/recommend' was found ($r=0.569$, part correlation 0.285 , $p=0.007$), and a weaker positive correlation between 'ease of use' and 'would use/recommend' ($r=0.517$, part correlation 0.181 , $p=0.079$). This may be interpreted to mean that the respondents' intention to use the system is due mainly to its usefulness and they are less concerned that the system is a little more challenging to use.

Usefulness of the Quiz and the scores achieved

The third version included a formative quiz, which tested students' learning of the names of anatomical structures tagged in LAHFS, thus giving students the opportunity to rehearse their knowledge (Edmunds et al., 2013) gained from LAHFS, and for the year 1 medical students, related to the learning objectives of the practical laboratory session at which the user test occurred. The question 'was the quiz useful as a check on understanding?' yielded a very positive response, 77 ± 18 (80). Behavioral rehearsal as an active learning technique has a positive relationship to

skills development (Edmunds et al., 2013; Rutherford-Hemming, 2012; Young et al., 2014).

Participants generally did well on the quiz, with average scores of 7.1 ± 2.6 (8) out of 10. This suggests that the students learned the material fairly well; however, there was not a pre-test / post-test design in this study. There was a moderate positive correlation ($r=0.443$) between participants' score on the quiz and their rating of the usefulness of the quiz. This might indicate that the system or quiz confirmed the user's knowledge on the topic.

5.2.2 Concluding Remarks on RQ1

[RQ1: What are undergraduate students' responses to and attitudes toward a haptic interface for learning anatomy?]

The first user test was well received by the group of users. As the system became more complex, this might have led to the degradation of ease of use of the system as it advanced. However, the system was still regarded as a useful tool for their learning.

These responses indicated that the haptic component of teaching anatomy was appreciated at the time of the experiment, and that simplified models may have resulted in a better experience. The decline in

rating may be attributed to the increasing complexity of the models and the interface.

This study with LAHFS agrees with the findings of others (Hess et al., 2014; Marangunić & Granić, 2015; Shroff et al., 2011), that ease of use and usefulness had a strong relation to the behavioural intention to use, and usefulness had a stronger correlation than ease of use.

The system implementation was done according to the cognitive load theory (Paas et al. 2003), which aims to keep learners' cognitive load to a minimum: for example, by letting the user turn the labels of parts on/off. Simplification of the task in learning as well as self-assessment (i.e. the quiz) was implemented as instructional techniques ensured performance and learning were not affected by possible extraneous loads on learners (Young et al., 2014).

This LAHFS research showed the acceptance of the system was higher when it was aligned well with relevant contents, self-directed learning (Bergman et al., 2013) and the self-assessment of the quiz in particular. Similarly, important factors for selecting CAL resources from the students' perspectives were cost, self-assessment, ease of use, and alignment with the curriculum (Choi-Lundberg et al., 2015).

Apparently, an option of self-assessment is in demand. Alignment with the curriculum was another factor raised in this research. For example, it was more welcomed when the content of experiment sessions aligned better with the topic covered in the class than otherwise.

The correlation between Quiz usefulness and System usefulness was very strong at $r=0.716$, $p < 0.001$. This may be interpreted to mean that students accept this type of system as a self-assessment tool. It can also be interpreted to mean that the students need formative assessment tools to rehearse and confirm their knowledge (Bergman et al., 2013).

However it is not possible to say from these user tests whether students would improve their ratings if they were to gain more experience with a haptic interface (thus reducing the operational difficulty), or whether long-term learning of anatomy was enhanced. The tests did not explore these factors, nor did it examine the use of a haptic interface in exploring the anatomical relationships amongst various organ systems, as the cardiovascular system module was separate from the lungs/liver module. Most of their results from the second try were better than the first. This does not necessarily mean that their learning was improved, however it may mean how quickly the students can get used to this new kind of interface. As the quiz was meant to provide formative feedback on learning, participants were given a second try at a question if they did not

get it correct on the first attempt, but further attempts were not allowed in the interest of time.

5.3 RESEARCH QUESTION 2

RQ2. What user characteristics influence his/her learning from and acceptance of LAHFS:

Summary of findings:

- Gender: Females rated 'performed well' with the system lower than males, but were more likely to 'use/ recommend the system'.
- Course/unit of study: Comparison between year 1 medical students and allied health sciences and education students enrolled in CXA273 showed 'system useful', 'quiz useful', and 'quiz score' was higher for the former group.
- Prior experience with haptic: no significant differences, but there was a trend for 'easy to use' to be rated higher by those with prior experience.
- Prior experience with 3D: no significant differences, but trends for 'perform well', 'system useful', 'easy to use', 'would use/recommend', and 'quiz useful' were rated higher by those with more prior experience with 3D.
- VARK%: There were no statistically significant correlations, but some interesting trends: K% (but not A%, R%) generally had small positive

correlations ($0.1 < r < 0.2$ except as noted) with 'performed well' ($r=0.232$), 'easy to use', 'would use/recommend', and 'quiz useful', but also 'mental & physical stress'. V% had small positive correlations with 'system useful' and 'quiz useful'.

5.3.1 Gender

There were some differences in VAS questions between genders (Figure 4-8), i.e. 'performed well' was rated lower by females, while they were more likely to use or recommend the system.

The female participants tended to judge themselves rather than the system, commenting "I didn't do well" rather than criticising the system. Interestingly, females scored 74% in the quiz whereas male students averaged 69% (this difference was not statistically different, and the median score for both genders was 80%), so this did not relate to actual performance in the quiz. This gender difference in perceived performance is at odds with the neutrality observed by Padilla-Meléndez, del Aguila-Obra and Garrido-Moreno (2012, p. 314), but accords with the findings of Ong and Lai (2006) in respect to females' lower rating of computer self-efficacy in the context of learning. Nevertheless females liked the use of

the system more than males so that they rated higher on 'recommendation to the university' and possible 'use of the system'.

5.3.2 Course/unit of study

Comparisons by participants' course/unit of study was less straightforward due to different cohorts testing different versions of the system. Relevant comparisons included the following:

- Version 1: Computing vs year 2 or year 3 Medical students
- Version 3: Year 1 Medical students vs Health sciences and Education students enrolled in CXA273
- Year 1 Medical students: Version 2 vs Version 3

5.3.2.1 *Version 1: Computing vs Year 2 or 3 Medical students*

There were no significant differences between Computing ($n=10$) and year 2 or 3 medical students ($n=8$) in user test version 1. The small sample sizes made it unlikely to detect differences between these two groups. Comparing across all versions and participants, computing students gave the highest ratings for 'system usefulness' and 'ease of use', but also reported the highest 'mental stress' and 'physical stress'.

Year 2 or 3 medical students saw this system as very useful and easy to use. Furthermore, their stress levels were the lowest out of any group.

This group had the highest acceptance of the system out of students studying biology-related fields; however the population was too small to draw any conclusion. The self-selection bias (the very low response rate of 8 of 230, which is 3.5%) may have led to participants who were highly likely to accept the system.

5.3.2.2 Version 3: Year 1 Medical Students vs the Allied Health Sciences and Education students enrolled in CXA273

Year 1 medical students rated 'system useful' and 'quiz useful' higher than the allied health sciences and education students enrolled in CXA273, and performed better in the quiz (Figure 4-12). This could be due to the closely related content of the practical laboratory sessions at which the user test occurred for year 1 medical students (introductory organ systems including cardiovascular, respiratory and digestive) compared to the unrelated CXA273 practical on the urinary (renal) system. However, the allied health sciences and education students enrolled in CXA273 had studied the cardiovascular, respiratory and digestive organ systems in previous weeks, so LAHFS would have provided a good opportunity for them to revise their understanding, particularly with end-of-semester exams approaching.

5.3.2.3 Year 1 Medical Students: Version 2 vs Version 3

Different cohorts of year 1 medical students tested version 2 and version 3 in 2012 and 2013 respectively. Version 2 had a total of 23 labelled structures, while version 3 had 27 labelled structures. Version 3 also included a quiz that randomly generated a list of 10 structures to identify from the learning module on heart and blood vessels (Table 3-2).

There were no statistically significant differences between year 1 medical students' ratings of versions 2 and 3; however, there were trends for 'easy to use' and 'would recommend' to be lower, and 'physical stress' and 'system useful' to be higher. The decline in 'would use/recommend' may have related to the different wording of the questions, as described previously. The higher 'usefulness' of the system, but also higher 'physical stress' and lower 'ease of use', might have been related to the quiz, which required students to click on the usually small structure to identify it, and also to click on a small menu button, 'next question'.

5.3.3 Prior experiences with haptic

The vast majority (83%) of participants had no prior experience with haptic devices. Most of the questions had similar ratings between those with and those without prior haptic experience (Figure 4-13), although there was a trend for those with prior experience to rate the system as

easier to use. The lack of a large difference suggests that this interface does not require any special skills to use. Anecdotally, most students were surprised and excited by the novel haptic sensation with the device.

5.3.4 Prior experiences with 3D

The participants had more previous experience with 3D than with haptic interfaces; 29% had no prior experience with 3D before, 39% had one to ten prior experiences, and 31% had more than ten. (Figure 4-14)

There were non-significant trends for participants with more prior experiences with 3D to rate 'performed well', 'system useful', 'easy to use', 'would recommend', and 'quiz useful' higher.

In the beginning of the trial, some students found it was hard to get used to a new dimension, *z*, which was the depth of the 3D setting. However participants generally quickly became adept at using the Phantom Omni to manipulate and identify objects. Nevertheless, as the LAHFS system includes 3-dimensional aspects, including rotation and moving objects along the *z*-axis, prior experience may improve user acceptance, as well as performance in the quiz, which was just significantly higher ($78\% \pm 21$ (80%) vs $59\% \pm 30$ (60%), $p=0.05$) in those with prior experiences than for those without. The 3D environment of the quiz may have put an

additional cognitive load on identifying structures, which led those with no prior experience to do worse in the quiz.

5.3.5 Learning styles

The LAHFS system includes prominent visual and haptic components; thus, the VARK learning styles instrument, which includes visual and kinaesthetic, as well as auditory and reading, dimensions was chosen as the learning styles instrument for this study. The VARK survey was administered to participants in user test 3 only.

One of the effective learning elements pointed out by Vaughn & Baker was to address learners' needs and understand their learning styles (2001). Providing only the most preferred learning style may not be the best option for learning (Vaughn & Baker, 2001); rather, available learning options are important in terms of availability of a range of resources and greater possibilities. Understanding individuals' preferred modality and providing relevant options are important (Urval et al., 2014).

The percentage of the Visual, Aural, Read/write, and Kinaesthetic styles (a %V, %A, %R, %K score) were determined for each participant. This was due to the small population of 43 participants who completed the VARK survey, so that categorisation into VARK categories would have resulted in

small numbers of participants in each of the 20 categories as described on the VARK website. The percentages allow correlations of this data with VAS scores.

None of the correlations between learning styles and VAS questions were significant. This means there is no prominent difference in learning styles and users' responses with LAHFS in this small sample. Nevertheless greater kinaesthetic (K%) participants had weak positive correlations with 'performed well', 'system useful', 'easy to use', 'would use/recommend', and 'quiz useful', but they also have positive correlation with 'mental and physical stress' (Table 4-5). While higher K% learners tended to rate the system higher, perhaps they found the haptic interface was not natural enough, hence rated mental and physical stresses higher.

Visual percentage (V%) had positive correlations with 'system useful' and 'quiz useful', whereas aural and read/write percentages were nearly all negatively correlated. This is not surprising since the system was very much visual and haptic oriented, with limited text (only names of structures) and no auditory component.

In surgical learning, where touch is directly linked to the skills required (Esteban et al., 2014), haptic feedback of learning anatomy will enhance

knowledge of organs and may lead into more practical assistance of learning for kinaesthetic learners.

5.3.6 Concluding Remarks on RQ2

Analysis with different elements shows that there is no significant difference in gender, previous experiences with haptic, and some of courses and units. Only significant difference found between MBBS year 1 and allied Health Science. It resulted significantly different between them for the system useful, quiz useful, and quiz result items. Only kinaesthetic learners are positively correlated with performed well and easy to use (Table 4-5 and 4-6).

5.4 RESEARCH QUESTION 3

RQ3. What elements of the haptic learning system influence user acceptance?

Clean, clear user interface design without complexity is an important element for acceptance by users. Additional factors include usefulness and relevance of the topic to the curriculum, and the desire for a variety of learning resources.

5.4.1 Elements of user acceptance

The 'easy to use' attribute declined from V1 through to V3, while 'system useful' decreased from V1 to V2, with little change between V2 and V3, which gave a bigger gap between 'useful' and 'easy to use' (Figure 4-1).

With all those elements we examined in this section (Technology in Learning, Haptic interface in particular, learning styles, and gender), TAM was the underlying model of theory. User satisfaction would be a retrospective assessment according to Lee and Lehto (2013). But it was a more anticipating factor based on the responses to 'system usefulness', 'system easy to use', and 'would you recommend' from this research with LAHFS. Although satisfaction is assessed already with 'usefulness' of the system and quiz and 'easy to use', in our case, 'would you recommend' was a more complementary question to anticipate the use of the system.

The results of the study indicated that students' perceived 'system useful' had a significant influence on their attitude towards usage (section 4.3.6.1).

The relevance of the topic to the curriculum or assessment will be another factor, which could be a part of perceived usefulness.

When the intention to use is low, then general assessment would be less positive as was the reason for CXA273. So a close relevance to the content

is crucial. If the experiment had happened during week 5 of CXA273 with the same content of main module and quiz, the acceptance might have been higher.

Perceived ease of use was not significantly predictive of either perceived usefulness or behavioral intention (Lee & Lehto, 2013), and the simplified version of the TAM worked well in predicting user acceptance by perceived usefulness and ease of use on behavioral intention (Venkatesh, 2000). A modified version of TAM removed the construct of attitude as a mediator but Venkatesh (2000) pointed out that “the simplified version of the TAM may be superior to the original model in predicting user acceptance, by including the direct effects of both perceived usefulness and ease of use on behavioral intention”.

At the time of the study of Lee & Lehto, the students had used the tool, YouTube, for at least one year already and that may influence perceived ease of use. However, usefulness was valued higher than ease of use in LAHFS, without prior experiences with haptic.

5.4.2 Concluding Remarks on RQ3

Effective learning in any discipline requires flexibility in learning options (Vaughn & Baker, 2001). This is particularly true in medicine with its busy

schedule. The LAHFS has the potential to provide flexibility with access to a 3D visual and haptic sensory learning resource.

How LAHFS was accepted as a useful learning resource was analysed based on the rankings of learning resources in the questionnaire. All the other resources listed, lectures, tutorials, and practical sessions, notes, textbooks, atlases, software, websites and other, were existing resources for the students. In contrast, LAHFS was a new resource, used for only about 10 – 15 minutes, and yet it ranked 4th amongst eight learning resources, significantly lower than face-to-face classes, class notes, and textbooks; and significantly above websites and other resources (Figure 4-15).

The present research confirmed that the traditional methods such as lectures, lab sessions, and textbooks and notes, were preferred learning options for students, as has been reported previously (Choi-Lundberg et al., 2015; Weber et al., 2012). However, this study found that many students rated the LAHFS, with its haptic technology, useful and easy to use.

The participants had a similar or higher preference for the computer-based haptic system compared to other available computer-based resources and atlases, a 'traditional' resource. The LAHFS could offer a

different, optional learning tool and flexibility of access outside of class time if this device is stationed in an accessible room.

Additional features such haptic systems could offer in the future are expanding. Already, haptic systems have been studied in various surgical training areas (Basdogan et al., 2004; Coles et al., 2011; Esteban et al., 2014; Fang et al., 2014; Tercero et al., 2013; Ullrich & Kuhlen, 2012; Wu et al., 2014). The current anatomy practical sessions at the University of Tasmania offer a variety of learning resources; LAHFS could be incorporated as an additional, optional resource. Not all students will find this is useful, but based on the generally high level of user acceptance, it is likely that many will. This is also confirmed with another study that showed self-directed study resources are highly welcomed by students, especially based on usefulness and ease of use (Choi-Lundberg et al., 2015).

However the device at this stage is not accessible easily, due to the cost (AU\$ 2,460 in 2011). The Phantom Omni is at the lower end in costing, but it provides 6 degrees of freedom sensing and 3 degrees of freedom force feedback. As the cost of technology drops, and given that the current and future generations of students are 'digital natives' (Prensky, 2001), it is time to introduce computer-based learning tools in the university learning environment with more advanced technology

incorporated. It is anticipated that various types of haptic devices under development will be available with reduced prices in the near future.

The instructional tools developed are to provide assistance in terms of accessibility and availability for the learner. In this defined context, LAHFS is an instructional technology that assists the learner's experiences, another optional way of learning.

5.4.3 Relevance of LAHFS to the laboratory practical topic

The direct relevance of the LAHFS topic to the laboratory session in which it was tested might have had an influence on how the students perceived its usefulness. This relates to one of variables, 'job relevance', i.e. the degree to which the technology is applicable, in the TAM context (Marangunić & Granić, 2015). When they used the system with the same topic area, the students found the system was more useful than otherwise: The Year 1 MBBS practical included the organ systems displayed in LAHFS (cardiovascular, respiratory, digestive). However, the CXA273 practical was about the urinary system. The Year 1 MBBS students' responses on 'system useful' ($p=0.013$), quiz useful ($p=0.012$) and quiz result ($p=0.031$) were higher.

As Design Research advances in a cyclic manner, it was inevitable to have different users and slightly different products in a cyclic incremental development. However the participants are all in common in terms of their standpoint as novice users of the haptic system.

5.4.4 Limitations of LAHFS and the Study

The LAHFS system, including their visual and haptic elements, was quite rudimentary, as they were aimed at students in the early stages of learning human anatomy. Further versions with higher fidelity anatomical models may increase usefulness for anatomy learning.

Student learning with LAHFS was only assessed with an immediate post-test, and was confounded with learning from the laboratory practical content for MBBS students and prior learning earlier in the semester of CXA273 students. A pre-test, post-test, delayed post-test design, with students randomised to LAHFS or other learning resources, at a time prior to the students studying the cardiovascular system, would better assess learning specifically from LAHFS and in comparison to more traditionally used learning resources.

One of limitations of this research is self-selection bias. Students who are interested in and more accepting of technology may have been more likely to volunteer to test the system; hence, their evaluation may have been more favourable than the general undergraduate student population. Although more medical students wanted to try the system, its use was limited to the set class time in user tests 2 and 3, and only one LAHFS was available.

Students self-selected to participate in the user tests, and thus may not be typical of the population of undergraduate students of human anatomy. Version 1 was tested by only 10 BComp students (who were not studying anatomy) and 8 MBBS students, the latter representing only a 3.5% response rate.

Versions 2 and 3 were tested by larger number of students than Version 1, and all participants in Version 2 and 3 were studying anatomy, with response rates in the range of 20-31%.

Another limitation of the present study was the relatively small number of participants ($n=89$ across three user tests). Larger numbers of participants may have resulted in many observed trends becoming statistically significant

It is difficult to provide the feel of small objects with a haptic response. It is more suitable for larger objects such as heart chambers, liver, and lungs than for fine blood vessels such as the left common carotid artery or the right subclavian vein.

In the first implementation of the system it calculated the internal characteristics of every object either visible or hidden thirty times a second. This required a great deal of processing power, and consequently system performance was slow. Later versions of the system eliminated these unnecessary calculations so making the system quicker and more responsive.

CHAPTER 6 CONCLUSIONS AND FUTURE WORK

6.1 CONCLUSIONS AND CONTRIBUTIONS OF THE RESEARCH

Undergraduate students' responses to a haptic interface for learning anatomy were generally favourable, with considerable variance in responses.

In order to find out what user characteristics and system elements influence learning from and acceptance of LAHFS, attitudes were studied based on responses to questionnaires.

There were no differences in the acceptance of the system based on prior experience with haptic devices, although there was a trend for '*ease of use*' to be rated higher with prior haptic experience. Similarly, more experience with 3D interfaces was associated with rating the LAHFS system as '*easier to use*', and with non-significant trends for higher ratings of '*performed well*', '*system useful*', '*would use/recommend*', and '*quiz*'

useful'. There was a learning curve in becoming accustomed to the LAHFS system, and prior experience with haptic or 3D systems may have facilitated adaptation and resulted in somewhat higher acceptance.

Although female students rated their performance with the system lower than males, they were more likely to use or recommend the system. Gender did not significantly influence perceptions of ease of use and usefulness of a haptic interface.

None of the correlations of percentage of visual, aural, read/write, or kinaesthetic learning styles with ratings of the system were statistically significant, although kinaesthetic percentage positively correlated with *'performed well', 'easy to use', 'quiz useful', and 'quiz result'*, but also with *'mentally and physically stressed'*. The lack of an auditory component or significant amounts of text (beyond labels) probably resulted in the participants with higher percentages of aural or read/write learning preferences tending to rate the system lower. Thus, students with a preference for kinaesthetic learning approaches may be more accepting of the LAHFS system.

The LAHFS system was ranked as the fourth favoured learning resource, after face-to-face classes, notes, and textbooks, and followed by atlases, software, websites, and 'other' resources (Table 4-7, Figure 4-15). The

LAHFS did not statistically differ in ranking to atlases and software, but was significantly higher ranked than websites and other learning resources, while being significantly lower ranked than face-to-face learning sessions and associated notes as well as textbooks. These findings confirm that the traditional learning resources such as lectures, tutorials, and practicals in both modes of face-to-face sessions and notes are valued highly. This also suggests that the LAHFS system could be a valued addition to the variety of learning resources offered to students to support their learning of anatomy.

Year 1 medical students rated the system and quiz as more useful than allied health sciences and education students enrolled in Anatomy & Physiology 2 (A&P2). This may be related to the medical students' better performance on the quiz, and/or due to better alignment of LAHFS with the learning objectives of the Year 1 MBBS practical than to the A&P2 practical at which their user tests were conducted. This issue could be further investigated by ensuring alignment of the LAHFS with the topic of laboratory practicals at which future user tests are conducted. Furthermore, this issue would not occur when this type of system is incorporated into laboratory practicals as another learning resource. Alignment of curriculum and technology is important, and technology yields the greatest learning benefits when it is used in a learner-centered way (Burns, 2013).

The design complexity of LAHFS affected user acceptance. Each successive version was more complex with more and smaller anatomical structures labelled and additional functions of the haptic device enabled in the present study. This resulted in ease of use being rated lower with successive versions of the system. The haptic interface should be simple to use and not demand significant attention or cognitive load to be effective in supporting learning. Hence, further development of haptic interfaces and additional studies of their acceptance should occur.

Generally, LAHFS was well accepted, and the students appreciated the quiz. Opportunities to rehearse knowledge through formative assessment should be incorporated into learning resources (Edmunds et al., 2013).

Virtual reality anatomy learning can be used to complement traditional methods of learning effectively (Codd and Chodhurry, 2011); the LAHFS provided an additional sensory modality of haptic feedback for students. With further development and greater realism of both visual and interface components of the system, the LAHFS may be a valued addition for anatomy learning experiences and enable anatomy curriculum improvement (Kish et al., 2013).

This study with LAHFS confirms that technology is well accepted by many students and may assist learning, but should not replace but rather complement current practices, as students vary in their preferences for learning resources (Choi-Lundberg et al., 2015), and some academics may be resistant to elimination of traditional teaching methods (Kazley et al., 2013).

‘Haptic(s)’ is a relatively new term, but its applications are expanding rapidly. The positive acceptance of the LAHFS system demonstrates another way of learning anatomy, with potential for further development. It suggests that adding a haptic sensory modality will enhance computer-based learning activities.

This system received a favourable acceptance from most of the users in this study. An initial outlay is required to adopt this type of system in medical and related disciplines; however, it may provide a cost-effective resource to students in such a crucial and expensive domain of training experts. This type of device is developing very quickly with other more realistic haptic interfaces, e.g., glove-based tools and their incorporation into effective learning experiences is expanding.

Much previous research relating to haptic devices in medical and health sciences has focused on advanced trainees learning surgical or procedural

skills. The present research suggests that incorporating haptic feedback into virtual anatomical models may be a useful strategy to provide multisensory information in learning anatomy at the undergraduate level. This study also found that system complexity is one factor that affects users' acceptance of the system. Furthermore, haptic suitability for kinaesthetic learners was confirmed.

6.2 RECOMMENDATIONS

With further development of haptic interface technology and reduction of cost, haptic systems should become a viable option for teachers of anatomy to include as an additional resource to assist their students in learning anatomy.

This study gives an important indication that this option of learning anatomy will enhance the learning experience and be generally well-accepted by many students.

6.3 SUGGESTIONS FOR FUTURE RESEARCH

The LAHFS system was accepted well by the users. More affordable and usable haptic devices and applications are already appearing. For

example, virtual gloves give more realistic haptic feedback with better affordability. Continual research in parallel with user tests and commercial bodies' involvement is anticipated.

LAHFS is constructive, contextual, and self-directed. Collaborative features can be added on later (Bergman et al., 2013), with multiple users can interact at the same time.

Providing accurate haptic feedback such as hardness and surface texture of organs would help students to understand additional relevant information about anatomical structures. This earlier experience might also transfer into the surgical domain later, both the haptic anatomical knowledge as well as familiarity with haptic devices, since haptic interfaces are becoming more common in surgical training.

Another further study could be on a different age group such as high school students. Much research has confirmed that age is a major role in the interaction with technology (Marangunić & Granić, 2015). With the advancement of computers and devices, virtual dissection is not far away, with the potential for haptic modality to be added to them. (Sigrist et al., 2013).

Future experiments could explore what aspects of the Phantom Omni interface influenced user acceptance and performance. Haptic feedback includes a combination of somatosensory (touch) sensation mediated by tactile receptors in the skin, and kinaesthetic (muscle sense) sensation, mediated by kinaesthetic receptors in muscles, tendons, and joints (Panait et al, 2009). For example, two conditions could be compared with participants randomly assigned to two groups, (a) the LAHFS as tested in the present study, vs. (b) the LAHFS with the haptic force feedback turned off, thus providing only somatosensory (touch) sensation and 'passive' kinaesthetic sensation of the weight of the stylus itself. This would address whether the active force feedback provided by the Phantom Omni influenced user acceptance. We would hypothesise that this feedback is an important component of the realism of the system, as it provides a sense of 'contact' with the organ, and its deformability or 'stiffness'. The influence of more natural interaction interfaces such as glove-based haptic systems may be compared with the single-point-of-contact stylus of the Phantom Omni, and again the influence of 'active' force feedback could be explored by turning this parameter on or off.

- Abbott, C., Brown, D., Evett, L., Standen, P., & Wright, J. (2011). *Learning difference and digital technologies: a literature review of research involving children and young people using assistive technologies 2007–2010*. Paper presented at the ESRC Seminar Series: Researching Assistive Technologies.
- Ackerman, M. J. (1998). The visible human project. *Proceedings of the IEEE*, 86(3), 504-511.
- Adams, J., Bertram, J., & McMenamin, P. (2015). Anatomy and Additive Manufacturing: Imaging Methods and 3D Printing in Anatomy Education and Research. *The FASEB Journal*, 29(1 Supplement), 692.612.
- Alessi, S. M., & Trollip, S. R. (2001). Multimedia for learning. *Methods and development*, 3.
- Alkhasawneh, E. (2013). Using VARK to assess changes in learning preferences of nursing students at a public university in Jordan: implications for teaching. *Nurse Educ Today*, 33(12), 1546-1549. doi:10.1016/j.nedt.2012.12.017
- Anderson, T., & Shattuck, J. (2012). Design-based research a decade of progress in education research? *Educational researcher*, 41(1), 16-25.
- Arevalo, C. R., Bayne, S. C., Beeley, J. A., Brayshaw, C. J., Cox, M. J., Donaldson, N. H., . . . Johnson, L. A. (2013). Framework for e-learning assessment in dental education: a global model for the future. *Journal of dental education*, 77(5), 564-575.
- Ayres, P. (2015). State - of - the - Art Research into Multimedia Learning: A Commentary on Mayer's Handbook of Multimedia Learning. *Applied Cognitive Psychology*, 29(4), 631-636.
- Basdogan, C., De, S., Kim, J., Muniyandi, M., Kim, H., & Srinivasan, M. (2004). Haptics in minimally invasive surgical simulation and training. *Computer Graphics and Applications, IEEE*, 24(2), 56-64.
- Bassil, Y. (2012). A simulation model for the waterfall software development life cycle. *arXiv preprint arXiv:1205.6904*.
- Battocchi, A., Gal, E., Sasson, A. B., Pianesi, F., Venuti, P., Zancanaro, M., & Weiss, P. (2008). Collaborative puzzle game-an interface for studying collaboration and social interaction for children who are typically developed or who have Autism Spectrum Disorder. *7th ICDVRAT with ArtAbilitation. ICDVRAT/University of Reading, UK*, 127-134.
- Baykan, Z., & Nacar, M. (2007). Learning styles of first-year medical students attending Erciyes University in Kayseri, Turkey. *Adv Physiol Educ*, 31(2), 158-160. doi:10.1152/advan.00043.2006

References

- Beauchamp, G., & Kennewell, S. (2010). Interactivity in the classroom and its impact on learning. *Computers & Education*, 54(3), 759-766.
- Bergman, E. M., Sieben, J. M., Smailbegovic, I., de Bruin, A. B., Scherpbier, A. J., & van der Vleuten, C. P. (2013). Constructive, collaborative, contextual, and self - directed learning in surface anatomy education. *Anatomical sciences education*, 6(2), 114-124.
- Black, J. B., Segal, A., Vitale, J., & Fadjo, C. L. (2012). Embodied cognition and learning environment design. *Theoretical foundations of learning environments*, 2, 198-223.
- Blikstein, P. (2013). *Multimodal learning analytics*. Paper presented at the Proceedings of the third international conference on learning analytics and knowledge.
- Boström, L., & Hallin, K. (2012). Learning Style Differences between Nursing and Teaching Students in Sweden: A Comparative Study. *International Journal of Higher Education*, 2(1). doi:10.5430/ijhe.v2n1p22
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2), 77-101.
- Brokelman, R. B., Haverkamp, D., van Loon, C., Hol, A., van Kampen, A., & Veth, R. (2012). The validation of the visual analogue scale for patient satisfaction after total hip arthroplasty. *European orthopaedics and traumatology*, 3(2), 101-105.
- Brydon-Miller, M., Greenwood, D., & Maguire, P. (2003). Why action research? *Action research*, 1(1), 9-28.
- Burke, P. F. (2013). Seeking Simplicity in Complexity: The Relative Value of Ease of Use (EOU) - Based Product Differentiation. *Journal of Product Innovation Management*, 30(6), 1227-1241.
- Burns, M. (2013). Success, failure or no significant difference: Charting a course for successful educational technology integration. *International Journal of Emerging Technologies in Learning*, 8(1), 38-45.
- Challis, B. (2013). Tactile interaction. *The Encyclopedia of Human-Computer Interaction*, 2nd Ed.
- Choi, K.-S., Sun, H., & Heng, P.-A. (2003). Interactive deformation of soft tissues with haptic feedback for medical learning. *IEEE transactions on information technology in biomedicine: a publication of the IEEE Engineering in Medicine and Biology Society*, 7(4), 358-363.
- Choi - Lundberg, D. L., Low, T. F., Patman, P., Turner, P., & Sinha, S. N. (2015). Medical student preferences for self - directed study resources in gross anatomy. *Anatomical sciences education*.
- Choudhary, R., Dullo, P., & Tandon, R. (2011). Gender differences in learning style preferences of first year medical students. *Pak J Physiol*, 7(2), 42-45.
- Clark, R. C., & Mayer, R. E. (2003). *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning* (1st ed.). San Francisco, CA: Pfeiffer.
- Codd, A. M., & Choudhury, B. (2011). Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal

References

- anatomy? *Anatomical sciences education*, 4(3), 119-125.
doi:10.1002/ase.214
- Codd, A. M., & Choudhury, B. (2011). Virtual reality anatomy: Is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? *Anatomical Sciences Education*, 4(3), 119-125.
doi:10.1002/ase.214
- Coghlan, D., & Brydon-Miller, M. (2014). *The SAGE Encyclopedia of Action Research*: Sage.
- Coles, T., Meglan, D., & John, N. W. (2011). The role of haptics in medical training simulators: a survey of the state of the art. *Haptics, IEEE Transactions on*, 4(1), 51-66.
- Collins, A., & Halverson, R. (2010). The second educational revolution: Rethinking education in the age of technology. *Journal of Computer Assisted Learning*, 26(1), 18-27.
- Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the learning sciences*, 13(1), 15-42.
- Cornwall, J., & Pollard, M. F. (2012). Evaluation of free i-applications for tertiary level gross anatomy education. *Australasian Medical Journal*, 5(4), 239-242.
Retrieved from <http://dx.doi.org/10.4066/AMJ.2012.1249>
- Davey, H. M., Barratt, A. L., Butow, P. N., & Deeks, J. J. (2007). A one-item question with a Likert or Visual Analog Scale adequately measured current anxiety. *Journal of clinical epidemiology*, 60(4), 356-360.
- Davis, A. M., Bersoff, E. H., & Comer, E. R. (1988). A strategy for comparing alternative software development life cycle models. *Software Engineering, IEEE Transactions on*, 14(10), 1453-1461.
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Management science*, 35(8), 982-1003.
- Dev, P., Montgomery, K., Senger, S., Heinrichs, W. L., Srivastava, S., & Waldron, K. (2002). Simulated medical learning environments on the internet. *Journal of the American Medical Informatics Association*, 9(5), 437-447.
- Dominguese, D. (2011). *Implementing Interactive Technology to Teach Clinical Anatomy*. Paper presented at the Society for Information Technology & Teacher Education International Conference.
- Edmunds, J. M., Kendall, P. C., Ringle, V. A., Read, K. L., Brodman, D. M., Pimentel, S. S., & Beidas, R. S. (2013). An examination of behavioral rehearsal during consultation as a predictor of training outcomes. *Administration and Policy in Mental Health and Mental Health Services Research*, 40(6), 456-466.
- Elliott, B. (2008). E-pedagogy and e-assessment.
- Esteban, G., Fernández, C., Conde, M. Á., & García-Peñalvo, F. J. (2014). *Playing with SHULE: surgical haptic learning environment*. Paper presented at the Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality.
- Evreinova, T. V., Evreinov, G., & Raisamo, R. (2008). A camera-joystick for sound-augmented non-visual navigation and target acquisition: a case study. *Universal Access in the Information Society*, 7(3), 129-144.

References

- Fang, T.-Y., Wang, P.-C., Liu, C.-H., Su, M.-C., & Yeh, S.-C. (2014). Evaluation of a haptics-based virtual reality temporal bone simulator for anatomy and surgery training. *Computer methods and programs in biomedicine*, 113(2), 674-681.
- Fleming, N. D. (1995). [I'm different; not dumb. Modes of presentation (VARK) in the tertiary classroom].
- Fleming, N. D. (2015, 18 June 2015).
- Fluck, A. (2003). *Integration or transformation: a cross-national study of information and communication technology in school education*. University of Tasmania.
- Gentry, C. G. (1995). Educational technology: A question of meaning. *Instructional technology: Past, present, and future*, 1-10.
- Gorjian, B., Alipour, M., & Saffarian, R. (2012). The effect of multisensory techniques on reading comprehension among pre-intermediate EFL learners: The case of gender. *Advances in Asian Social Science*, 1(2), 192-196.
- Gould, D., Kelly, D., Goldstone, L., & Gammon, J. (2001). Examining the validity of pressure ulcer risk assessment scales: developing and using illustrated patient simulations to collect the data INFORMATION POINT: Visual Analogue Scale. *Journal of clinical nursing*, 10(5), 697-706.
- Guyatt, G. H., Townsend, M., Berman, L. B., & Keller, J. L. (1987). A comparison of Likert and visual analogue scales for measuring change in function. *Journal of chronic diseases*, 40(12), 1129-1133.
- Hess, T. J., McNab, A. L., & Basoglu, K. A. (2014). Reliability generalization of perceived ease of use, perceived usefulness, and behavioral intentions. *Management Information Systems Quarterly*, 38(1), 1-28.
- Hjalmarson, M., Nelson, J. K., & Lorie, C. Teaching as a Design Process: A Framework for Design-based Research in Engineering Education. *Journal of the American Association of Aging*, 26, 1.
- Hoffman, H., & Vu, D. (1997). Virtual reality: teaching tool of the twenty-first century? *Academic Medicine*, 72(12), 1076-1081.
- Howell, J. N., Conatser, R. R., Williams, R. L., Burns, J. M., & Eland, D. C. (2008). The virtual haptic back: a simulation for training in palpatory diagnosis. *BMC medical education*, 8(1), 14.
- Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education*, 55(3), 1171-1182. doi:10.1016/j.compedu.2010.05.014
- Ingole, A., Kumar, D. S. A., Bahattere, V., & Chaware, S. (2015). Application of Multimedia Design Principle in Learning Anatomy and Physiology. *Indian Journal of Anatomy*, 4(1), 17.
- Issa, N., Mayer, R. E., Schuller, M., Wang, E., Shapiro, M. B., & DaRosa, D. A. (2013). Teaching for understanding in medical classrooms using multimedia design principles. *Med Educ*, 47(4), 388-396.
- Issa, N., Schuller, M., Santacaterina, S., Shapiro, M., Wang, E., Mayer, R. E., & DaRosa, D. A. (2011). Applying multimedia design principles enhances learning in medical education. *Med Educ*, 45(8), 818-826.

References

- Itkowitz, B., Handley, J., & Zhu, W. (2005). *The OpenHaptics™ toolkit: a library for adding 3D Touch™ navigation and haptics to graphics applications*. Paper presented at the Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2005. World Haptics 2005. First Joint.
- Jia, D., Bhatti, A., Nahavandi, S., & Horan, B. (2013). Human performance measures for interactive haptic-audio-visual interfaces. *Haptics, IEEE Transactions on*, 6(1), 46-57.
- Kazley, A. S., Annan, D. L., Carson, N. E., Freeland, M., Hodge, A. B., Seif, G. A., & Zoller, J. S. (2013). Understanding the use of educational technology among faculty, staff, and students at a medical university. *TechTrends*, 57(2), 63-70.
- Keedy, A. W., Durack, J. C., Sandhu, P., Chen, E. M., O'Sullivan, P. S., & Breiman, R. S. (2011). Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. *Anatomical sciences education*, 4(2), 84-91.
- Khot, Z., Quinlan, K., Norman, G. R., & Wainman, B. (2013). The relative effectiveness of computer-based and traditional resources for education in anatomy. *Anatomical sciences education*, 6(4), 211-215.
doi:10.1002/ase.1355
- Kinnison, T., Forrest, N. D., Frea, S. P., & Baillie, S. (2009). Teaching bovine abdominal anatomy: Use of a haptic simulator. *Anatomical sciences education*, 2(6), 280-285.
- Kirschner, F., Kester, L., & Corbalan, G. (2010). Cognitive load theory and multimedia learning, task characteristics, and learning engagement: The current state of the art.
- Kish, G., Cook, S. A., & Kis, G. (2013). Computer - assisted learning in anatomy at the International Medical School in Debrecen, Hungary: A preliminary report. *Anatomical sciences education*, 6(1), 42-47.
- Lee, D. Y., & Lehto, M. R. (2013). User acceptance of YouTube for procedural learning: An extension of the Technology Acceptance Model. *Computers & Education*, 61, 193-208.
- Lewis, T. L., Burnett, B., Tunstall, R. G., & Abrahams, P. H. (2014). Complementing anatomy education using three-dimensional anatomy mobile software applications on tablet computers. *Clin Anat*, 27(3), 313-320.
doi:10.1002/ca.22256
- Lingard, L., & Kennedy, T. J. (2010). Qualitative research methods in medical education. In T. Swanwick (Ed.), *Understanding Medical Education: Evidence, Theory and Practice* (1st ed., pp. 323-335). Chichester, West Sussex, UK: Wiley-Blackwell.
- Marangunic, N., & Granic, A. (2015). Technology acceptance model: a literature review from 1986 to 2013. *Universal Access in the Information Society*, 14(1), 81-95.
- Marker, D. R., Juluru, K., Long, C., & Magid, D. (2011). Strategic improvements for gross anatomy web-based teaching. *Anatomy research international*, 2012.

References

- McLachlan, J. C., & Patten, D. (2006). Anatomy teaching: ghosts of the past, present and future. *Medical Education*, 40(3), 243-253. doi:10.1111/j.1365-2929.2006.02401.x
- McNulty, J. A., Sonntag, B., & Sinacore, J. M. (2009). Evaluation of computer-aided instruction in a gross anatomy course: a six-year study. *Anatomical sciences education*, 2(1), 2-8. doi:10.1002/ase.66
- Morris, D., Tan, H., Barbagli, F., Chang, T., & Salisbury, K. (2007). *Haptic feedback enhances force skill learning*. Paper presented at the EuroHaptics Conference, 2007 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics 2007. Second Joint.
- Mustafa, A. G., Allouh, M. Z., Mustafa, I. G., & Hoja, I. M. (2013). Anatomy learning styles and strategies among Jordanian and Malaysian medical students: the impact of culture on learning anatomy. *Surgical and Radiologic Anatomy*, 35(5), 435-441. doi:10.1007/s00276-012-1067-z
- Newell, F. N., & Mitchell, K. J. (2015). Multisensory integration and cross-modal learning in synaesthesia: A unifying model. *Neuropsychologia*.
- Nguyen, N., Nelson, A. J., & Wilson, T. D. (2012). Computer visualizations: factors that influence spatial anatomy comprehension. *Anatomical sciences education*, 5(2), 98-108. doi:10.1002/ase.1258
- Nicholson, D. T., Chalk, C., Funnell, W. R., & Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Med Educ*, 40(11), 1081-1087. doi:10.1111/j.1365-2929.2006.02611.x
- Nuzhat, A., Salem, R. O., Quadri, M. S. A., & Al-Hamdan, N. (2011). Learning style preferences of medical students: a single-institute experience from Saudi Arabia. *International Journal of Medical Education*, 2, 70-73. doi:10.5116/ijme.4e36.d31c
- Oh, E., & Reeves, T. C. (2010). The implications of the differences between design research and instructional systems design for educational technology researchers and practitioners. *Educational Media International*, 47(4), 263-275.
- Ong, C.-S., & Lai, J.-Y. (2006). Gender differences in perceptions and relationships among dominants of e-learning acceptance. *Computers in Human Behavior*, 22(5), 816-829.
- Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist*, 38(1), 1-4.
- Padilla-Meléndez, A., del Aguila-Obra, A. R., & Garrido-Moreno, A. (2013). Perceived playfulness, gender differences and technology acceptance model in a blended learning scenario. *Computers & Education*, 63, 306-317.
- Page, L. K. (1994). Professional development in higher education: A theoretical framework for action research: Wiley Online Library.
- Palombi, O., Pihuit, A., & Cani, M. P. (2011). 3D Modeling of branching vessels from anatomical sketches: towards a new interactive teaching of anatomy: Interactive virtual blackboard. *Surgical and Radiologic Anatomy*, 33(7), 631-636. doi:10.1007/s00276-011-0827-5

References

- Panait, L., Akkary, E., Bell, R. L., Roberts, K. E., Dudrick, S. J., & Duffy, A. J. (2009). The role of haptic feedback in laparoscopic simulation training. *Journal of Surgical Research*, 156(2), 312-316.
- Pang, P. S., Collins, S. P., Sauser, K., Andrei, A. C., Storrow, A. B., Hollander, J. E., . . . Raev, D. (2014). Assessment of Dyspnea Early in Acute Heart Failure: Patient Characteristics and Response Differences Between Likert and Visual Analog Scales. *Academic Emergency Medicine*, 21(6), 659-666.
- Park, J. S., Chung, M. S., Hwang, S. B., Lee, Y. S., Har, D.-H., & Park, H. S. (2005). Visible Korean human: improved serially sectioned images of the entire body. *Medical Imaging, IEEE Transactions on*, 24(3), 352-360.
- Plomp, T. (2009). Educational design research: An introduction. *An introduction to educational design research*, 9-35.
- Ponnampalam, G. (2013). Multi modal Virtual Anatomy Learning Tools for Medical Education using recent advances in IT. *The Official Journal of the Federation of American Society for Experimental Biology*, 27(1_MeetingAbstracts), 960.917.
- Preece, D., Williams, S. B., Lam, R., & Weller, R. (2013). "Let's get physical": advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. *Anatomical sciences education*, 6(4), 216-224. doi:10.1002/ase.1345
- Preece, D., Williams, S. B., Lam, R., & Weller, R. (2013). "Let's Get Physical": Advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. *Anatomical Sciences Education*, 6(4), 216-224. doi:10.1002/ase.1345
- Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the horizon*, 9(5), 1-6.
- Puente dura, R. (2010). SAMR and TPACK: Intro to advanced practice. Retrieved February, 12, 2013.
- Reeves, T. C. (2000). Enhancing the worth of instructional technology research through "design experiments" and other development research strategies. *International Perspectives on Instructional Technology Research for the 21st Century*, 27, 1-15.
- Reeves, T. C. (2006). Design research from a technology perspective. *Educational design research*, 1(3), 52-66.
- Rogers, G. (2004). History, learning technology and student achievement Making the difference? *Active Learning in Higher Education*, 5(3), 232-247.
- Royce, W. W. (1970). *Managing the development of large software systems*. Paper presented at the Proceedings of IEEE Western Electronic Show and Convention.
- Ruthenbeck, G. S., & Reynolds, K. J. (2015). Virtual reality for medical training: the state-of-the-art. *Journal of Simulation*, 9(1), 16-26. doi:<http://dx.doi.org/10.1057/jos.2014.14>
- Rutherford-Hemming, T. (2012). Simulation methodology in nursing education and adult learning theory. *Adult Learning*, 23(3), 129-137.
- Sakellariou, S., Ward, B. M., Charissis, V., Chanock, D., & Anderson, P. (2009). Design and implementation of augmented reality environment for complex anatomy

References

- training: inguinal canal case study *Virtual and Mixed Reality* (pp. 605-614): Springer.
- Säljö, R. (2010). Digital tools and challenges to institutional traditions of learning: technologies, social memory and the performative nature of learning. *Journal of Computer Assisted Learning*, 26(1), 53-64. doi:10.1111/j.1365-2729.2009.00341.x
- Saltarelli, A. J., Roseth, C. J., & Saltarelli, W. A. (2014). Human cadavers vs. multimedia simulation: A study of student learning in anatomy. *Anatomical Sciences Education*, 7(5), 331-339. doi:10.1002/ase.1429
- Saltarelli, A. J., Roseth, C. J., & Saltarelli, W. A. (2014). Human cadavers Vs. multimedia simulation: A study of student learning in anatomy. *Anatomical sciences education*, 7(5), 331-339. doi:10.1002/ase.1429
- Samarakoon, L., Fernando, T., Rodrigo, C., & Rajapakse, S. (2013). Learning styles and approaches to learning among medical undergraduates and postgraduates. *BMC medical education*, 13(1), 42.
- Schvartzman, S., Salisbury, K., Silva, R., & Girod, S. (2014). Surgical Simulation and Education. *International Journal of Computer Assisted Radiology and Surgery*, 9(1), S123-S138.
- Shaikh, S. T. (2015). Cadaver Dissection in Anatomy: The Ethical Aspect. *Anatomy & Physiology: Current Research*, 2015.
- Shams, L., & Seitz, A. R. (2008). Benefits of multisensory learning. *Trends in cognitive sciences*, 12(11), 411-417.
- Shroff, R., Deneen, C., & Ng, E. (2011). Analysis of the technology acceptance model in examining students' behavioural intention to use an e-portfolio system. *Australasian Journal of Educational Technology*, 27(4), 600-618.
- Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic bulletin & review*, 20(1), 21-53.
- Sugand, K., Abrahams, P., & Khurana, A. (2010). The anatomy of anatomy: a review for its modernization. *Anatomical sciences education*, 3(2), 83-93. doi:10.1002/ase.139
- Tan, S., Hu, A., Wilson, T., Ladak, H., Haase, P., & Fung, K. (2012). Role of a computer-generated three-dimensional laryngeal model in anatomy teaching for advanced learners. *The Journal of Laryngology & Otology*, 126(04), 395-401.
- Teklemariam, H. G., & Das, A. (2015). A case study of phantom omni force feedback device for virtual product design. *International Journal on Interactive Design and Manufacturing*, 1-12.
- Temkin, B., Acosta, E., Malvankar, A., & Vaidyanath, S. (2006). An interactive three-dimensional virtual body structures system for anatomical training over the internet. *Clin Anat*, 19(3), 267-274. doi:10.1002/ca.20230
- Tercero, C. R., Najdovski, Z., Ikeda, S., Nahavandi, S., & Fukuda, T. (2013). *Haptic feedback in endovascular tele-surgery simulation through vasculature phantom morphology changes*. Paper presented at the World Haptics Conference (WHC), 2013.

References

- Terzis, V., & Economides, A. A. (2011). Computer based assessment: Gender differences in perceptions and acceptance. *Computers in Human Behavior*, 27(6), 2108-2122.
- Thomas, M. P. (2013). The role of simulation in the development of technical competence during surgical training: a literature review. *International Journal of Medical Education*, 4, 48-58. doi:10.5116/ijme.513b.2df7
- Toth-Cohen, S. (1995). Computer-assisted instruction as a learning resource for applied anatomy and kinesiology in the occupational therapy curriculum.
- Ullrich, S., & Kuhlen, T. (2012). Haptic palpation for medical simulation in virtual environments. *Visualization and Computer Graphics, IEEE Transactions on*, 18(4), 617-625.
- Urval, R. P., Kamath, A., Ullal, S., Shenoy, A. K., Shenoy, N., & Udupa, L. A. (2014). Assessment of learning styles of undergraduate medical students using the VARK questionnaire and the influence of sex and academic performance. *Adv Physiol Educ*, 38(3), 216-220.
- van Merriënboer, J. J. G., & Sweller, J. (2010). Cognitive load theory in health professional education: Design principles and strategies. *Medical Education*, 44(1), 85-93. doi:10.1111/j.1365-2923.2009.03498.x
- Vanags, T., Budimlic, M., Herbert, E., Montgomery, M. M., & Vickers, T. (2012). Showercap Mindmap: a spatial activity for learning physiology terminology and location. *Adv Physiol Educ*, 36(2), 125-130.
- VARK Learn Limited. (2016). VARK: A guide to learning styles, and research & statistics. Retrieved from <http://vark-learn.com/> and <http://vark-learn.com/introduction-to-vark/research-statistics/>
- Vaughn, L., & Baker, R. (2001). Teaching in the medical setting: balancing teaching styles, learning styles and teaching methods. *Med Teach*, 23(6), 610-612.
- Venkatesh, V. (2000). Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model. *Information systems research*, 11(4), 342-365.
- Walling, D. R. (2014). Using Tablet Technology for Multisensory Learning *Designing Learning for Tablet Classrooms* (pp. 89-95): Springer.
- Wang, S.-K., Hsu, H.-Y., Reeves, T. C., & Coster, D. C. (2014). Professional development to enhance teachers' practices in using information and communication technologies (ICTs) as cognitive tools: Lessons learned from a design-based research study. *Computers & Education*, 79, 101-115.
- Weber, J., Hincke, M., Patasi, B., Jalali, A., & Wiper-Bergeron, N. (2012). The Virtual Anatomy Lab: an eDemonstrator pedagogical agent can simulate student-faculty interaction and promote student engagement. *Medical Education Development*, 2(1), 5. doi:10.4081/med.2012.e5
- Wu, F., Chen, X., Lin, Y., Wang, C., Wang, X., Shen, G., . . . Heng, P. A. (2014). A virtual training system for maxillofacial surgery using advanced haptic feedback and immersive workbench. *The International Journal of Medical Robotics and Computer Assisted Surgery*, 10(1), 78-87.
- Yamine, K., & Violato, C. (2015). A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. *Anatomical Sciences Education*, 8(6), 525-538. doi:10.1002/ase.1510

References

- Yeom, S. (2011). *Augmented reality for learning anatomy*. Paper presented at the Australasian Society for Computers in Learning in Tertiary Education, Hobart.
- Yeom, S., Choi-Lundberg, D., Fluck, A., & Sale, A. (2013). *User Acceptance of a Haptic Interface for Learning Anatomy*. Paper presented at the 7th Multi Conference on Computer Science and Information System, e-Learning, Prague, Czech Republic.
- Young, J. Q., Van Merriënboer, J., Durning, S., & Ten Cate, O. (2014). Cognitive load theory: Implications for medical education: AMEE guide no. 86. *Med Teach*, 36(5), 371-384.
- Yushkevich, P. A., Piven, J., Hazlett, H. C., Smith, R. G., Ho, S., Gee, J. C., & Gerig, G. (2006). User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. *Neuroimage*, 31(3), 1116-1128. doi:10.1016/j.neuroimage.2006.01.015



[QRcode for Soonja Yeom](#)

APPENDIX 1 – ETHICS APPROVAL DOCUMENTS

Ethics approval

Information sheet

Consent form

Social Science Ethics Officer
Private Bag 01 Hobart
Tasmania 7001 Australia
Tel: (03) 6226 2763
Fax: (03) 6226 7148
Katherine.Shaw@utas.edu.au



HUMAN RESEARCH ETHICS COMMITTEE (TASMANIA) NETWORK

8 November 2011

Dr Andrew Fluck
Faculty of Education
Locked Bag 1307
Launceston Tasmania

Student Researcher: Soon ja Yeom

Dear Dr Fluck

Re: FULL ETHICS APPLICATION APPROVAL
Ethics Ref: H0011743 - User acceptance for learning anatomy with augmented reality
in 3D

We are pleased to advise that the Tasmania Social Sciences Human Research Ethics Committee approved the above project on 6 November 2011.

Please note that this approval is for four years and is conditional upon receipt of an annual Progress Report. Ethics approval for this project will lapse if a Progress Report is not submitted.

The following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval.

1. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval, to ensure the project is conducted as approved by the Ethics Committee, and to notify the Committee if any investigators are added to, or cease involvement with, the project.
2. Complaints: If any complaints are received or ethical issues arise during the course of the project, investigators should advise the Executive Officer of the Ethics Committee on 03 6226 7479 or human.ethics@utas.edu.au.
3. Incidents or adverse effects: Investigators should notify the Ethics Committee immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.

A PARTNERSHIP PROGRAM IN CONJUNCTION WITH THE DEPARTMENT OF HEALTH AND HUMAN SERVICES

Appendix 1

4. Amendments to Project: Modifications to the project must not proceed until approval is obtained from the Ethics Committee. Please submit an Amendment Form (available on our website) to notify the Ethics Committee of the proposed modifications.
5. Annual Report: Continued approval for this project is dependent on the submission of a Progress Report by the anniversary date of your approval. You will be sent a courtesy reminder closer to this date. Failure to submit a Progress Report will mean that ethics approval for this project will lapse.
6. Final Report: A Final Report and a copy of any published material arising from the project, either in full or abstract, must be provided at the end of the project.

Yours sincerely

Katherine Shaw
Acting Executive Officer



A PARTNERSHIP PROGRAM IN CONJUNCTION WITH THE DEPARTMENT OF HEALTH AND HUMAN SERVICES

Private Bag 87 Hobart
Tasmania 7001 Australia
Phone (03) 6226 2900 Fax (03) 6228 2913
Email Andrew.Fluck@utas.edu.au
www.cis.utas.edu.au



SCHOOL OF COMPUTING AND INFORMATION SYSTEMS

PARTICIPANT INFORMATION SHEET SOCIAL SCIENCE/ HUMANITITES RESEARCH

User acceptance for learning anatomy with augmented reality in 3D

Invitation

You are invited to participate in a research study into how a computer generated 3D Augmented System can help studying anatomy. The study is being conducted by Soon-ja Yeom of School of Computing and Information Systems.

1. 'What is the purpose of this study?'

The purpose is to investigate whether flexible interaction with a 3D learning environment can enhance your understanding of human abdomen anatomy.

2. 'Why have I been invited to participate in this study?'

You are eligible to participate in this study because you are studying the topic area.

3. 'What does this study involve?'

You may initially explore the provided system as freely as you like. The main functions are

- finding out names of organs that you need to locate and memorise
- disassembling and reassembling parts to understand the inter relationship among the various organs
- self-testing

You can then learn the required aspect of anatomy using the worksheet.

It is important that you understand that your involvement in this study is voluntary. While we would be pleased to have you participate, we

respect your right to decline. There will be no consequences to you if you decide not to participate, and this will not affect your study/result. If you decide to discontinue participation at any time, you may do so without providing an explanation. All information will be treated in a confidential manner, and your name will not be used in any publication arising out of the research. All of the research will be kept in a password-protected computer of the researcher.

4. Are there any possible benefits from participation in this study?

It is possible that you will notice a suitable method of learning for the topic. This may lead to improved performance in terms of learning different part of organs as well as the inter-relationship of organs. We will be interested to see if you experience any other benefits from your participation.

If we are able to take the findings of this small study and link them with a wider study, the result may be valuable information for others.

5. Are there any possible risks from participation in this study?

There are no specific risks anticipated with participation in this study. However, if you find that you are becoming distressed or tired, you will be advised to receive support from an assistant during the session or alternatively, we will arrange for you to see a counsellor at the University of Tasmania at no expense to you.

6. What if I have questions about this research?

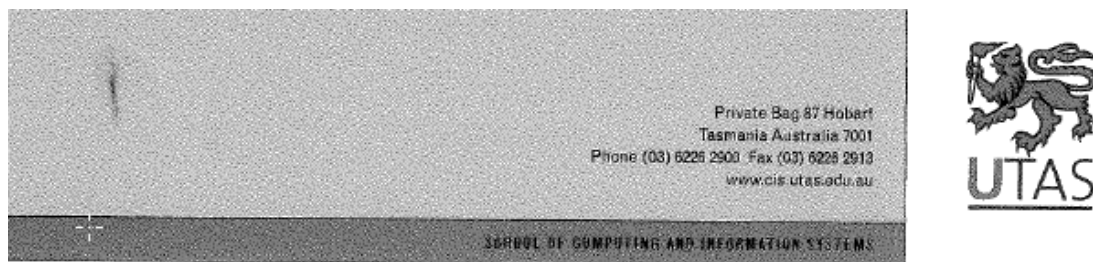
If you would like to discuss any aspect of this study please feel free to contact either Dr. Andrew Fluck on 6324 3284, or email to Andrew.fluck@utas.edu.au or Soon-ja Yeom on 6226 2963 or email to s.yeom@utas.edu.au. We would be happy to discuss any aspect of the research with you. Once we have analysed the information we will be mailing / emailing you a summary of our findings. You are welcome to contact us at that time to discuss any issue relating to the research study.

This study has been approved by the Tasmanian Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email

Appendix 1

human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. You will need to quote [*HREC project number*].

**Thank you for taking the time to consider this study.
If you wish to take part in it, please sign the attached consent form.
This information sheet is for you to keep.**



PARTICIPANT CONSENT FORM

User acceptance for learning anatomy with a tactile (haptic) interface :

- U
N
I
V
E
R
S
I
T
Y
O
F
T
A
S
M
A
N
I
A
1. I agree to take part in the research study named above.
 2. I have read and understood the 'Information Sheet' for this study.
 3. The nature and possible effects of the study have been explained to me.
 4. I understand that the study involves using a computer system with tactile (haptic) interface to explore a virtual anatomical model and complete a short quiz and completing questionnaires including demographic information, my experience with the system and interface, and learning styles. It may take 30 to 40 minutes, but I may stop at any point.
 5. I understand that participation involves no specific risks, but if I become distressed, unwell or tired, I may stop the using the system and interface, and I should advise the researcher or other UTAS staff member.
 6. I understand that all research data will be securely stored on the University of Tasmania premises for five years from the publication of the study results or completion of the researcher's (Soonja Yeom's) PhD, whichever occurs later, and will then be securely destroyed.
 7. Any questions that I have asked have been answered to my satisfaction.
 8. I agree that research data gathered from me for the study may be published in such a way that I cannot be identified as a participant.
 9. I understand that the researchers will maintain my confidentiality and that any information I supply to the researchers will be used only for the purposes of the research.
 10. I understand that my participation is voluntary and that I may withdraw at any time without any effect. I understand that I will not be able to withdraw my data after completing the questionnaires, as these will be collected anonymously.

Name of Participant: _____

Signature: _____

Date: _____

APPENDIX 2 – COPY OF THE QUESTIONNAIRE

INCLUDING VARK QUESTIONS

Appendix 2

Questionnaires used in user tests

	UT1	UT2	UT3
1	Subject no.	Subject no.	Subject no.
2	Age	Age	Age
3	Gender	Gender	Gender
4		Email address	Course of study (degree program)
5	Length of computing use	Length of computing use	Length of computing use
6	How long have you been using a computer?	How long have you been using a computer?	How long have you been using a computer?
7	How often do you use a computer?	How often do you use a computer?	How often do you use a computer?
8	Haptic Experiences	Haptic Experiences	Haptic Experiences
9	Do you have previous experience with using a <u>haptic</u> interface?	Do you have previous experience with using a <u>haptic</u> interface?	Do you have previous experience with using a tactile (haptic) interface, excluding mobile phones?
10	Xbox 360 Kinect?	Xbox 360 Kinect?	
11	Do you have previous experience with using 3D interfaces or 3D software (e.g., 3D games, 3D graphics software tools, Virtual Reality Systems, Nintendo Wii, Sony MOVE)	Do you have previous experience with using 3D interfaces or 3D software (e.g., 3D games, 3D graphics software tools, Virtual Reality Systems, Nintendo Wii, Sony MOVE)	Do you have previous experience with using 3D interfaces or 3D software (e.g., 3D games, 3D graphics software tools, Virtual Reality Systems, Nintendo Wii, Sony MOVE)
12	Augmented Reality of Mixed Reality?		
	Performance	Performance	Performance

Appendix 2

	UT1	UT2	UT3
1	<u>Were you performing well</u> with the given task with the given interface?	<u>Were you performing well</u> with the given task with the given interface?	<u>Were you performing well</u> with the system? **
	Usefulness	Usefulness	Usefulness
2	<u>Was the given interface useful</u> for completing the given task?	<u>Was the given interface useful</u> for completing the given task?	<u>Was the system useful</u> for exploring the anatomical region?
	Easiness	Easiness	Easiness
3	<u>Was it easy</u> to perform the given task with the given interface?	<u>Was it easy</u> to perform the given task with the given interface?	Was it easy to use the system to explore the anatomical region?
	Mentally stressed	Mentally stressed	Mentally stressed
4	<u>Did you get mentally stressed</u> while performing the task with the given interface?	<u>Did you get mentally stressed</u> while performing the task with the given interface?	<u>Did you get mentally stressed</u> while using the system?
	Physically stressed	Physically stressed	Physically stressed
5	<u>Did you get physically stressed</u> while performing the task with the given interface?	<u>Did you get physically stressed</u> while performing the task with the given interface?	<u>Did you get physically stressed</u> while using the system?
		Preference/recommendation	Preference/recommendation
6		Would you use this system as an aid of learning when it is fully developed?	Would you recommend the University use a system based on this one?
7			Was the quiz useful as a check on understanding?

Appendix 2

	UT1	UT2	UT3
8			What were the best aspects of the system?
9			What aspects of the system were most in need of improvements? What suggestions do you have for improvement?
10			What other features would you like to see in the system to aid your learning?
11			Rank the learning sessions or resources
			VARK Learning Styles



This questionnaire has been removed for
copyright reasons

Appendix 2



© Copyright Version 7.8 (2014) held by VARK Learn Limited, Christchurch, New Zealand.

Reproduced with permission of the author Neil Flemming June 18 2015 obtained.

APPENDIX 3 – USER TEST 3

CAM101, Week 10, Practical – medical imaging, gross anatomy, & organ systems 2

10 May 2012

Practical – Medical imaging, gross anatomy, and organ systems 2 (lymphatic, cardiovascular, respiratory, digestive, and urinary)

Learning Objectives:

Identify the organs of the lymphatic, cardiovascular, respiratory, digestive, and urinary systems, on anatomical models and medical imaging studies.
Identify the anatomical regions of the body, the body cavities, and the organs and organ systems they contain; and use directional terms to describe their anatomical relationships.

Specimens for stations:

Station 1: torso model UA197, half head models HN AVN1, AVN2, spleen etc on stick model UA147; Netter 266 (249); Gosling atlas 3rd ed Fig 1.33; Weir 118d, 125c; 4 computers for Anatomy & Physiology Revealed CDs (lymphatic system), Anatomedia General Anatomy CDs (systems, 58, 59, 72)

Station 2: torso model UA197/1, thorax model UA397/1, heart models UA312, 312/1, upper limb model UA349, lower limb model UA345; light box, chest radiograph; Weir 2nd ed 88, 95i, 96b, 97e, 101j, 103e

Station 3: torso model UA197/2, thorax model UA397, half head model HN AVN/3, sagittal and coronal head model UA 198/1, deep head model UA354; Weir 2nd ed 88, 96b, 97e, 27f, 23h, 18b

Station 4: torso model UA400, half head model HN AVN/4, deep head model UA353, sagittal and coronal head model UA 198, digestive system models UA346, 346/1, stomach models UA175, 175/1, liver models UA MSH, MSH/1, pancreas etc on stick model UA147/1; Weir 2nd ed 18a, 19b, 23h, 93d, 98i, 118b, 118d, 119h, 127a, 128, 129, 148b

Station 5: urinary system etc model UA411, male sagittal pelvis model UA129/1, female sagittal pelvis model UA141, kidney models UA KOS, KOS/1, kidney on board models UA196, 196/1; Weir 2nd ed 119h, 121a, 125a, 138b, 148b, 153f, 158d

Before you begin:

You will find it useful to prepare before the practical class: read through the worksheet and attempt to answer some of the questions. You can then spend more time examining the resources provided at the practical. It would be a good idea to bring the Tortora & Derrickson *Principles of Anatomy & Physiology* text and Weir et al *Imaging Atlas of Human Anatomy* to the practical.

We suggest you work in small groups. The practical is designed for self-directed learning; demonstrators are available to assist you if you encounter difficulties. Answer the questions on this worksheet as you examine the resources available at each station. As you examine the medical images (radiograph, CT, MRI), compare these to the anatomical models, and attempt to work out the identity of the labeled structures (answers are on the back of the medical images). You do not hand in the worksheet at the end of the practical, but you should use it to revise the material covered.

You may start at any station (lab bench), and progress in order (eg, station 4→5→1→2→3) about every 20 minutes. Please handle models with care, and if you disassemble them, reassemble them when finished, thank you.

Station 1: Lymphatic / Immune system

You may find the 2 CDs useful for learning about the lymphatic system: Anatomy & Physiology Revealed (APR), lymphatic system; and Anatomedia, General Anatomy, systems, 58, 59, 72.

The lymphatic/immune system includes lymph (a fluid), lymphatic vessels, cells (lymphocytes, dendritic cells, macrophages, etc), and various lymphatic tissues and organs, located in all regions of the body. The lymphatic system defends the body against microorganisms, foreign substances, and cancerous cells, and is important in body fluid balance. What volume of excess extracellular fluid (ECF) is returned to the bloodstream each day by the lymphatic system, having 'leaked' from the plasma into the ECF?

Excess tissue fluid flows into lymphatic capillaries and then larger lymph vessels, which accompany nerves, arteries, and veins in neurovascular bundles. Lymphatic/immune system cells, microorganisms, and cancer cells can also enter lymph vessels. At certain locations in the body, lymph vessels enter lymph nodes, where the lymph is 'filtered' and immune responses may be activated. See the APR CD for the structure of lymph nodes.

Identify some of the major lymph node groups and vessels. Where does the thoracic duct return lymph to the bloodstream? Lymph from which regions of the body flows through the thoracic duct?

Lymph from which regions of the body instead flows through the right lymphatic duct?

In the pharynx, which is near the entrance to the respiratory and digestive tracts, there are collections of lymphoid tissue called the tonsils. These are located in the nasopharynx, on the posterior surface of the tongue, and just inferior to the posterior part of the palate, which separates the nasal cavity and oral cavity.

Practical – Medical imaging, gross anatomy, and organ systems 2 (lymphatic, cardiovascular, respiratory, digestive, and urinary systems)

Learning Objectives:

Identify the organs of the lymphatic, cardiovascular, respiratory, digestive, and urinary systems, on anatomical models and medical imaging studies.
Identify the anatomical regions of the body, the body cavities, and the organs and organ systems they contain; and use directional terms to describe their anatomical relationships.

Specimens for stations:

Station 1: torso model UA197, half head models HN AVN1, AVN2, spleen etc on stick model UA147; Netter 249; Gosling atlas 3rd ed Fig 1.33; Weir 118, 125;

Station 2: torso model UA197/1, thorax model UA397/1, heart models UA312, 312/1, upper limb model UA349, lower limb model UA345; light box, chest radiograph; Weir 88, 95, 96, 97, 101, 103

Station 3: torso model UA197/2, thorax model UA397, half head model HN AVN/3, sagittal and coronal head model UA 198/1, deep head model UA354; Weir 88, 96, 97, 27, 23, 18

Station 4: torso model UA400, half head model HN AVN/4, deep head model UA353, sagittal and coronal head model UA 198, digestive system models UA346, 346/1, stomach models UA175, 175/1, liver models UA MSH, MSH/1, pancreas etc on stick model UA147/1; Weir 18, 19, 23, 93, 98, 118, 119, 127, 128, 129, 148

Station 5: urinary system etc model UA411, male sagittal pelvis model UA129/1, female sagittal pelvis model UA141, kidney models UA KOS, KOS/1, kidney on board models UA196, 196/1; Weir 119, 121, 125, 138, 148, 153, 158

Note: Weir page references are 2nd edition. See table for similar 3rd, 4th edition. Netter plate reference is 1st edition. See table for similar 4th, 5th ed

Before you begin:

You will find it useful to prepare before the practical class: read through the worksheet and attempt to answer the questions. You can then spend more time examining the resources provided at the practical while reviewing the questions.

We suggest you work in small groups. The practical is designed for self-directed learning; demonstrators are available to assist you if you encounter difficulties. It would be a good idea for your group to bring a copy of Marieb & Hoehn *Human Anatomy & Physiology* text and Weir et al *Imaging Atlas of Human Anatomy* to the practical. Answer (or review your answers to) the questions on this worksheet as you examine the resources available at each station. As you examine the medical images (radiograph, CT, MRI), compare these to the anatomical models, and attempt to work out the identity of the labeled structures (answers are on the back of the medical images). You do not hand in the worksheet at the end of the practical, but you should use it to revise the material covered.

You may start at any station (lab bench), and progress in order (eg, station 4→5→1→2→3) about every 20 minutes. Please handle models with care, and if you disassemble them, reassemble them when finished, thank you.

Station 1: Lymphatic / Immune system

Identify the lymphatic system structures on the models and prints provided as you go through the questions.

The lymphatic/immune system includes lymph (a fluid), lymphatic vessels, cells (lymphocytes, dendritic cells, macrophages, etc), and various lymphatic tissues and organs, located in all regions of the body. The lymphatic system defends the body against microorganisms, foreign substances, and cancerous cells, and is important in body fluid balance.

What volume of excess extracellular fluid (ECF) is returned to the bloodstream each day by the lymphatic system, having 'leaked' from the plasma into the ECF?

Excess tissue fluid flows into lymphatic capillaries and then larger lymph vessels, which accompany nerves, arteries, and veins in neurovascular bundles. Lymphatic/immune system cells, microorganisms, and cancer cells can also enter lymph vessels. At certain locations in the body, lymph vessels connect to lymph nodes, where the lymph is 'filtered' and immune responses may be activated. See Marieb & Hoehn Figure 20.4 Lymph Node.

Identify major lymph node groups, including inguinal nodes (lymph from lower limb), various iliac nodes (pelvic structures), lateral aortic and other groups of lymph nodes along the aorta (abdominal structures), axillary nodes (upper limb), and cervical nodes (head and neck).

Lymph from which regions of the body flows to the thoracic duct?

Lymph from which regions of the body instead flows to the right lymphatic duct?

Where do the thoracic duct and right lymphatic duct return lymph to the bloodstream?

APPENDIX 4 - PAPERS PUBLISHED

PUBLISHED IN THE PROCEEDINGS OF ASCILITE IN 2011

Yeom S. 'Augmented Reality for Learning Anatomy' In G. Williams, N. Brown, & B. Cleland (Eds.), *Changing Demands, Changing Directions. Proceedings ascilite Hobart 2011*

PUBLISHED IN THE UNIVERSITY OF TASMANIA IN 2012

Yeom S, Fluck A, Sale A, Choi-Lundberg D, 'Exploring augmented reality for sustainable delivery of anatomy teaching and learning', *Teaching Matters 2012 - Conference Handbook*, 4th December 2012, Launceston, Tasmania, pp. 39. (2012)

PUBLISHED IN THE PROCEEDINGS OF THE E-LEARNING CONFERENCE IN 2013

The e-learning conference was part of the Multi Conference on Computer Science and Information Systems - presented there and awarded best paper status.

Yeom S, Choi-Lundberg D, Fluck A, Sale A, 'User Acceptance of a Haptic Interface for Learning Anatomy', *Proceedings of the IADIS International*

Conference E-Learning 2013, 22-26 July 2013, Prague, Czech Republic, pp. 239-246. ISBN 978-972-8939-88-5 (2013)

PUBLISHED TO INTERACTIVE TECHNOLOGY AND SMART
EDUCATION (ITSE)

Yeom, S., Choi-Lundberg, D., Fluck, A. and Sale, A. 'Factors influencing undergraduate students' acceptance of a haptic interface for learning gross anatomy'. *Interactive Technology and Smart Education* 14(1): 50-66.

<http://dx.doi.org/10.1108/ITSE-02-2016-0006>



Augmented Reality for Learning Anatomy

Soon-ja Yeom

School of Computing and Information Systems
University of Tasmania

Learning anatomy requires students to memorise a great deal of information and contextualize this within the range of body functions. Visualising the relationships in three dimensions of various organs and their interdependent functions is a major difficulty in this task. The system described in this paper is a development to assist students by providing an augmented reality version of the anatomical details under investigation that provides a structured learning approach to the material. This is a research project to investigate whether augmented reality (AR) with haptics is an effective tool to learn anatomy while providing equitable access to more engaging experiences.

Keywords: Anatomy, three dimensions, learning, interactive, computer, engagement.

Introduction

This research project is to investigate how effective learning experiences can be improved with a technology, called Augmented Reality (AR) with haptics. Generally speaking technology-aided learning provides flexible accessibility. An intuitive interactive method like AR with haptics is expected to provide more engaging and effective learning experiences.

Research background

Difficulty in Learning Anatomy

Anatomy can be a very important subject as fundamental towards many relevant fields, such as health science. (Dominguese, 2011; Sakellariou et. al., 2009). Contemporary educational methods for teaching complex anatomical regions are considered inadequate as they typically lack the depiction of a 3D spatial tissue in a three dimensional manner. As such, the majority of explanatory illustrations are diagrammatic, 2D representations of pre-determined angles of depiction (Sakellariou et. al., 2009). This usually requires a number of images to provide full description of 3D objects in a 2D way. Unfortunately it has made anatomy a difficult area to gain the necessary knowledge.

It is well known that people learn in different modes. Some people might learn better in, for example, a kinaesthetic way. However, this mode is usually restricted because of the current limits of the conventional learning environment including online learning with multi-media resources even with interaction. Due to these

Appendix 4

restrictions, learners have to adapt their way of learning to fit the circumstances of provision. However as technology advances, we can give access to new modes of learning. Also learners' acceptance and usage of technology has grown in a dramatic way.

One of the prominent problems in learning anatomy is that it is impossible for the trainee to investigate in depth the layered structures, their spatial relations and visit these complex structures from different angles that might enlighten their perception and understanding (Sakellariou et al., 2009). There can't be a perfect teaching alternative to current education. All the efforts are to improve a limited area or two with the assistance of technology. One way to overcome current limitations would be through Augmented Reality (AR). Sakellariou et al. (2009) pointed out that a virtual reality system with haptic feedback was found more engaging, interesting, easy to use and more efficient in elucidating spatial inter-relationships of structures.

Augmented Reality with Haptics in Anatomy

3D DVDs and interactive online learning systems are very common as auxiliary learning tools nowadays. The technology has advanced to augmented reality with an extra enhancement of haptic feedback. Many researchers (Liao et al., 2010; Nicolson et al., 2006; Temkin et al., 2006) have experimented with the use of augmented reality systems in different parts of anatomy. Sugand et al. (2010) noted that virtual simulations can be effective for university students to visualize and interact with internal organs. Moreover haptic feedback with kinesthesia and tactility provides palpatory training. Virtual Haptic Back (Howell et al., 2008) and the Haptic Cow (Kinnison et al., 2009) are unusual examples where haptic systems were evaluated for teaching. Both systems are highly accepted by students.

As Billingham (2002) noted, AR technology is suitable for application in education where this technology is a valuable and interactive tool in the academic process. A principal value of educational experiences in AR is the ability to support a smooth transition between two environments that are reality and virtuality.

Rosli et al. (2010) mentioned that AR was accepted as a tool to be more interesting and to develop learners' understanding of human organs further than the textbook from a survey of primary school students. Rosli et al. (2010) quotes "other science experiences also enhance the students to construct their intellect, thinking skill (Martin et al. 2009) and make them more confident to manipulate the machine". Likewise, the AR system will help the students gain enough practice with a close look and feel of the target anatomical part as a stepping-stone. The system may not be a perfect method of learning; however it is a tool to minimize the gap between reality and the virtual world.

In summary, it is evident that educational effects (Nischelwitzer et al., 2007; Marshall, 2007; Chien et al., 2010) encourage AR with haptics to be a medium to deliver training in 3D-oriented topic areas, but it has been neither widely experimented with nor evaluated. Although Augmented Reality haptic interfaces provide very intuitive methods for viewing three dimensional information, it has been less used in AR applications (Billinghurst et al., 2009) such as anatomy.

Research aims

The main purpose of the current project is to investigate the use of interactive 3D anatomy pictures with haptic feedback to teach and test anatomy knowledge, of the abdomen in particular, and to compare the results with other existing learning methods such as 2D images, models (wet or freeze-dried specimens and bones), and interactive resources (web, CD/DVD).

Appendix 4

Preliminary survey

Students enrolled in an anatomy unit were surveyed about their experiences of learning and applying anatomy. This was conducted informally over about 1.5 hours with the lecturer and a half an hour with 23 students (12 female, 6 international).

Conventionally the main resources for learning anatomy are textbooks, images (from textbooks, Computed Tomography (CT) scans or Magnetic Resonance Imaging (MRI) type of radiological images, and computer based images), integrated practical sessions (self-directed worksheets are used with models, e.g. dissemble & assemble models), and cadaver examinations that could be the most natural way of learning with haptic/kinesthetic experiences. The cadaver session is run with a group of 3-4 students to dissect the body, and then the group presents findings at a tutorial. Students spend up to 24 hours over 6 tutorials. Each student has 8 hours of dissection.

The students were asked:

- What aspect of learning anatomy do you find most difficult?
- What is your usual resource to study anatomy? Why? (e.g. textbooks, DVDs with animations, anything else)
- What are the limitations with which you wish to enhance the resources?

A fortunate and interesting point is that the identified difficulties in learning anatomy are same from both the lecturer and also the group of students. Both agreed that the main difficulties are applying 2D concepts to 3D spatial practice.

The following points were gathered from feedback sheets on the most difficult aspects of learning anatomy. Students had difficulty with:

- visualization of what they have learned in lectures; 2D materials are not easy to reconstruct in 3D world
- visualizing and applying knowledge practically in clinical conditions
- relationships (separate organs are understood but fitting them together is difficult); the relationship of each organ to its surrounding structures
- dissection of cadaver could be one of best learning options (only a few students mentioned this), but too complicated, so sometimes confusing; limited time access only.
- They mentioned their preference to have a 3D version of the images in textbooks
- and 3D zooming in interactive software to explore deeper layers such as vessels and/or nerve structure.

Thirteen students mentioned the limitations of 2D presentation while a few other students commented indirectly about 2D issues of putting the separate organs together in more clinical/practical sense.

It was surprising that although DVDs and online resources are well developed, they did not seem to be utilized well. One of the reasons might be cost. Another issue for not being accepted by users could be another layer of learning the tool itself. Despite all the efforts to create a transparent user interface, there is a big gap between the tool and user acceptance of it.

These computer-based resources have different pedagogical approaches as well as varying technologically.

System description

Current learning of anatomy consists of 2D coloured images (i.e. textbooks), e-resources (similar with textbooks but interactivity is added on), and cadaver dissection. An expensive cadaver option may not be a best option for learning. In spite of its cost and the difficulty of providing multiple learning opportunities with it, there are still gaps between what we can learn from it and what we can apply to clinical situations. The first image is an example of an image in a textbook. The last two images are used by the new haptic interaction system. The 3D images are rotatable and zoomable with a haptic interface (See Figure 1 for examples).

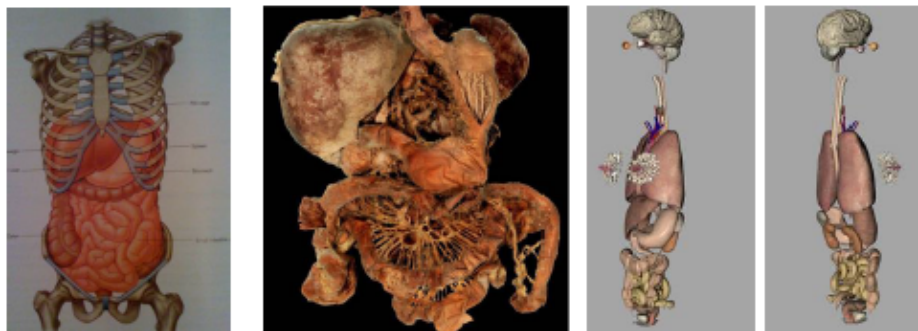


Figure 1: Image from textbook, image of cadaver, 3D images from haptic interactive system

When a student's eyes view 2D images in a textbook, they are looking at a static image which has been drawn and coloured in a specific way. The image contains a 3D model taken from a set angle with a particular status where colour-coding may distinguish digestive and blood circulatory systems for instance. Sometimes these static images are more realistic, and are based on cadavers.

By contrast, in the proposed system, the student will be able to view the organ from any angle and at any magnification. Augmented information superimposed on the anatomical visual models will display further explanations about the function and structure of each organ. Different functions will enable the student to select from colouring schemes or cadaver-like views. Different layers of organs, blood vessels, nerves, can also be selected.

Haptic technology provides the sense of touch and controls of computer system through force (kinesthetic) or tactile feedback. Haptic feedback provides another dimension to understanding anatomy efficiently. The Phantom Omni (Figure 2) is one of the relatively cheap haptic devices available. Effects provide a way to render forces to the haptic device to simulate arbitrary sensations. Force effects can be started and stopped or triggered in response to events, like touching a shape or pressing a button on the haptic device. Unlike shape rendering, effects will persist until stopped or until the duration has elapsed for trigger effects. This device provides 6 degrees of freedom to drag, rotate, zoom-in and out, and touch. By pressing an organ which is displayed on the monitor students can compare different sensations and hardness of parts of organs or inside and outside of an organ. Other programmable functions such as dissection can be added to the system.

Also one of the main difficulties in understanding anatomy is the gap between illustrations *per se* in textbooks or learning resources and the actual body or cadavers. By implementing augmented reality, various conditions with shapes and colours can be displayed at users' selection.

This study will explore these new affordances of technology and evaluate their effectiveness in learning.

Methods

The current “integrated practical” anatomy learning session consists of five (5) work benches allocated with different resources. An additional work bench will be added for this experiment. The system will be developed with Visual Studio 2010 in C++. OpenGL will be used to create high quality 3D images. A Phantom Omni robotic tool will provide haptic feedback with 6 degrees of freedom and will utilise the Openhaptics tool kit (Itkowitz, Handley & Zhu, 2005) to interface with the anatomical visualisation data. In order to develop augmented representation of 3D information, marker-less augmented reality will be adapted. Instead of creating markers, the extracted patterns of the images from the textbook will retrieve the information to be superimposed.

A user-trial experiment is designed in an activity-based curriculum. A mixed experimental research design will be used to evaluate participants’ practical examination scores as well as their perception of the computer program’s effectiveness in helping them learn anatomy in the form of questionnaires and video recording. The user survey with questionnaires and video recording are currently undergoing the ethics approval.

In order to test user acceptance by human users in the subject area, two different interfaces will be implemented. One interface is to use a haptic device such as Phantom Omni (Figure 2) that provides different type of haptic feedback to the user depending on his selected activity. The other interface is to use the same system with commercially available game device, Xbox 360 Kinect. This will provide an interface with fingertip control (Figure 3), but without haptic feedback.



Figure 2: Phantom Omni robotic arm with ‘touch feedback’

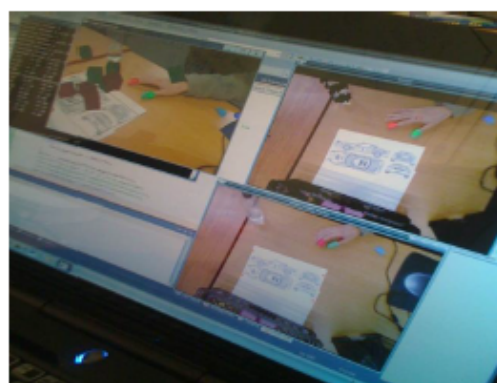


Figure 3: Xbox 360 Kinect detects coloured fingertips

The effectiveness of the AR system will be analysed by comparison of learning achievement measured by conventional academic assessment. User acceptance will be judged from videos showing how students used the system, and logs of their progress through the structured learning sequence.

Conclusion

This paper has described a problem in learning anatomy and how this project will aim to overcome some of the difficulties. Augmented reality is a relatively new area of research, so implementation and investigation are developing fields with emerging methodologies. Some comparisons of training using AR in the discipline of anatomy have shown promising results, with simulated human body organs providing better learning experiences (Leblanc et al., 2010). Activities in the museum sector have also shown that three dimensional objects can be better appreciated using a haptic interface (Butler & Neave, 2008) so this aspect of the current project appears promising. One novel feature of the proposed system is to incorporate a structured learning sequence based upon the anatomy lecturer's worksheets which will direct students through a series of investigations using explicit teaching. This will be followed by unstructured investigations using the affordances of the technology, and finally by an interactive quiz to verify learning. These aspects provide a good reason to hope the system will be effective when compared to traditional learning techniques.

Acknowledgements

The project is supported by a Teaching Development Grant from the University of Tasmania.

References

- Billingshurst, M. (2002). Augmented Reality in Education. *New Horizons for Learning*, www.newhorizons.org/strategies/technology/billingshurst.htm
- Billingshurst, M., Kato, H. & Myojin, S. (2009). Advanced Interaction Techniques for Augmented Reality Applications. Shumaker, R. (Ed.): *Virtual and Mixed Reality, LNCS 5622*, pp 13-22 2009
- Butler, M. & Neave, P. (2008). Object appreciation through haptic interaction. *Proceedings ASCILITE Melbourne 2008*. <http://www.ascilite.org.au/conferences/melbourne08/procs/butler-m.pdf>
- Chien, C. Chen, C. & Jeng, T. (2010). An Interactive Augmented Reality System for Learning Anatomy Structure. *IMECS 2010, March 17-19, 2010 Hong Kong Proceedings of the International MultiConference of Engineers and Computer Scientists 2010 Vol I*, pp 370- 375
- Dominguese, D. (2011). Implementing Interactive Technology to teach Clinical Anatomy. *Proceedings of SITE 2011*, Nashville, USA.
- Itkowitz, B., Handley, J. & Zhu, W. (2005). The OpenHapticsToolkit: A Library for Adding 3D Touch™ Navigation and Haptics to Graphics Applications. *Proceedings of the First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. <http://www.computer.org/comp/proceedings/whc/2005/2310/00/23100590.pdf>
- Leblanc, F. Champagne, B. J. Augestad, K. M. Neary, P. C. Senagore, A. J. Ellis, C. N. & Delaney, C. P. (2010). A Comparison of Human Cadaver and Augmented Reality Simulator Models for Straight Laparoscopic Colorectal Skills Acquisition Training. *Journal of the American College of Surgeons* 211(2) 250-255
- Liao, H. Inomata, T. Sakuma, I. & Dohi, T. (2010). 3-D Augmented Reality for MRI-Guided Surgery Using Integral Videography Autostereoscopic Image Overlay. *IEEE Transactions on Biomedical Engineering*, Vol. 57, No. 6, June 2010
- Marshall, P. (2007). Do Tangible Interface enhance learning? Chapter 4 Learning through physical interaction *TEI08*, 15-17 Feb 2008, Baton Rouge, LA, USA
- Nicolson, D. Chalk, C. Robert, W. Funnell, J. & Daniel, S. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Medical Education* 2006; 40:1081-1087
- Nischelwitzer, A. Lenz, F. Searle, G. & Holzinger, A. (2007). Some Aspects of the Development of Low-Cost Augmented Reality Learning Environments as Examples for Future Interfaces in Technology Enhanced Learning. Stephanidis, C. (Ed.): *Universal Access in HCI, Part III, HCII2007, LNCS 4556*, pp. 728-737 2007 © Springer-Verlag Berlin Heidelberg 2009
- Rosli H. Baharom, F. Harryizman, H. Ali A. Daud, Y. Haslina, M. & Norida Mhd, D. (2010). Using augmented reality for supporting learning human anatomy in science subject for Malaysian primary school. *Proceedings of Regional Conference on Knowledge Integration in ICT*.

Appendix 4

- Sakellariou, S. Ward, B. Charissis, V. Chanock, D. & Anderson, P. (2009). Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study. In R. Shumaker (Ed.): *Virtual and Mixed Reality*, LNCS 5622, pp. 605–614, 2009. © Springer-Verlag Berlin Heidelberg 2009
- Sugand, K. Abrahams, P. & Khurana, A. (2010). The Anatomy of Anatomy: A Review for Its Modernization. *Anatomical Sciences Education* March/April 2010
- Temkin, B. Acosta, E. Malvankar, A. & Vaidyanath, S. (2006). An Interactive Three-Dimensional Virtual Body Structures System for Anatomical Training Over the Internet. *Clinical Anatomy* 19:267-274 (2006)

Author Contact Details:

Soon-ja Yeom S.Yeom@utas.edu.au Please cite as: Yeom, S. (2011). Augmented Reality for Learning Anatomy. In G. Williams, P. Statham, N. Brown & B. Cleland (Eds.), *Changing Demands, Changing Directions. Proceedings ascilite Hobart 2011*. (pp.1377-1383).

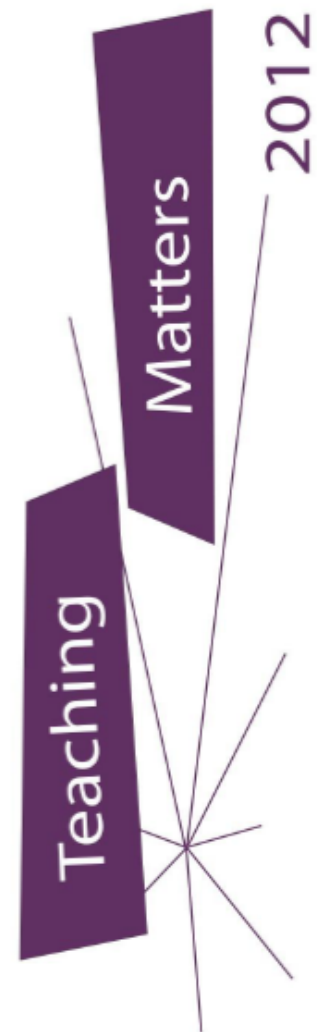
<http://www.ascilite.org.au/conferences/hobart11/procs/Yeom-concise.pdf>

Copyright © 2011 Soon-ja Yeom.

The author(s) assign to ascilite and educational non-profit institutions, a non-exclusive licence to use this document for personal use and in courses of instruction, provided that the article is used in full and this copyright statement is reproduced. The author(s) also grant a non-exclusive licence to ascilite to publish this document on the ascilite web site and in other formats for the *Proceedings ascilite Hobart 2011*. Any other use is prohibited without the express permission of the author(s).

© 2011 [The University of Tasmania](#), [ascilite](#) and the authors of individual articles.
Proceedings Editors: G. Williams, P. Statham, N. Brown & B. Cleland

ISBN Program Booklet: 978-1-86295-643-8 published by the University of Tasmania
ISBN Proceedings USB: 978-1-86295-644-5 published by the University of Tasmania



Sustaining Futures: Considering sustainability across the learning and teaching divide

4th December, 2012

School of Architecture and Design
Inveresk Campus
University of Tasmania

Appendix 4

Exploring augmented reality for sustainable delivery of anatomy teaching and learning

Soonja Yeom, Andrew Fluck, Arthur Sale and Derek Choi-Lundberg

Anatomy is a crucial subject in medicine, nursing, paramedicine and health sciences. There are a variety of learning resources available for anatomy; however, they are not necessarily utilized effectively due to the different learning styles of learners. More powerful, cheaper computers may provide a platform for sustainable, virtual environments that provide flexible options for student learning.

This is an on-going Design Research project to assist students in learning anatomy in a multisensory manner through a haptic interface to observe and manipulate 3D virtual organs. Humans naturally work in multisensory surroundings, and we hypothesize a multisensory virtual learning environment will be effective in learning anatomy. The intention of the system is to provide an alternative, sustainable learning resource. A prototype with the haptic interface was tested twice by a group of our medicine students. Students found the interface useful, and reported low stress levels while using the prototype. Teaching Development Grant 2011.

USER ACCEPTANCE OF A HAPTIC INTERFACE FOR LEARNING ANATOMY

Soonja Yeom¹, Derek Choi-Lundberg², Andrew Fluck³ and Arthur Sale¹

¹*School of Computing and Information Systems, University of Tasmania, Australia
Private Bag 100 Hobart, Tasmania, Australia*

²*School of Medicine, University of Tasmania, Australia, Private Bag 34 Hobart, Tasmania, Australia*

³*School of Education, University of Tasmania, Australia, Locked Bag 1307 Launceston, Tasmania, Australia*

ABSTRACT

Visualizing the structure and relationships in three dimensions (3D) of organs is a challenge for students of anatomy. To provide an alternative way of learning anatomy engaging multiple senses, we are developing a force-feedback (haptic) interface for manipulation of 3D virtual organs, using design research methodology, with iterations of system implementation, formative evaluation, and cyclic enhancements. In the present study, we aimed to determine the user acceptance of the haptic interface for exploring anatomical structures and relationships. Undergraduate computing (n=10) and medical (n=35) students from the University of Tasmania, Australia, who volunteered to try two iterations of the system (n=18 and 27 in two separate user tests) reported on anonymous questionnaire with quantitative and qualitative questions that the system was easy to use, useful for learning, and neither physically nor mentally stressful. We conclude that many medical students would accept a haptic interface for manipulating 3D virtual organs as an aid to learning anatomy. Further development of the system will involve development of learning and assessment modules, and we plan to evaluate the system's usefulness in promoting learning of anatomy.

KEYWORDS

Anatomy, haptic interface, technology-enhanced learning, higher education, medical education

1. INTRODUCTION

Efforts to improve learning experiences with technology have been actively pursued for decades (Reiser, 2001). Different teaching strategies and learning resources vary in effectiveness for learners with different learning styles (Murphy et al., 2004, Dobson, 2009); thus, offering a variety of learning options is pedagogically sound. This article describes the initial stages of development and evaluation of a system for exploring three-dimensional (3D) anatomical structure and relationships of human organs with haptic feedback.

As students of human biology may have only limited time to learn from real human organs or realistic 3D physical (eg, plastic) models, such a system provides an additional option for exploring 3D anatomical structures, making use of new technological opportunities to enhance learning experiences through activating multiple sensory systems of the learner. Students have reported difficulty in learning anatomy from 2D resources such as textbook diagrams (Yeom, 2011). Providing a 3D model with haptic feedback reduces the gap between a learning system and reality. When information is presented in a multisensory format, it improves learning and memory ability (Shams and Seitz, 2008). A display device and a controlling device are the main computer peripherals required for this system. This study investigated the acceptance of a haptic system with 3D anatomical models for learning anatomy by undergraduate computing and medical students at the University of Tasmania (UTAS).

3D simulations with interaction in anatomy, radiological imaging, and surgery is an active research area (Behringer et al., 2003, Chien, 2010, Dieperink, 2006, Nicholson et al., 2006, Sakellariou et al., 2009, Tan et al., 2012, Temkin et al., 2006, Yushkevich et al., 2006, Liao et al., 2010). For example, learning from a 3D computer model and standard two-dimensional (2D) images of laryngeal anatomy did not differ, but learners preferred the 3D model (Tan et al., 2012). In contrast, Nicholson et al. (2006) found learning outcomes were

improved with 3D computer models of the ear compared to traditional 2D images, possibly due to greater interactivity and complexity of the 3D computer models vs the 2D images. Computer-generated 3D models may be particularly effective in providing visualization of anatomy that is hard to represent through traditional 2D images (Sakellariou et al., 2009). User responses to virtual reality (VR) with a haptic interface were "positive and the majority of users found the VR system more engaging, interesting and easy to use and more efficient in elucidating spatial inter-relationships of structures" (Sakellariou et al., 2009). However it is unclear whether the positive results were due to 3D models produced in VR, the haptic interface, or a combination of both. The effectiveness of a haptic interface may not be easy to measure due to the complexity of the system, with interactivity, quality of the system, and learning outcome goals important additional variables (San Diego et al., 2012).

As educational research incorporating haptic technology for learning human anatomy in health fields is currently mostly limited to advanced, post-graduate trainees, our research aims to determine if a haptic interface can assist undergraduate medical students in learning anatomy. Our overarching research question is to determine whether learning anatomy in a 3D system with a force-feedback palpable (haptic) control will enhance anatomy learning and transfer of knowledge into realistic settings. As a work-in-progress, research sub-questions are to investigate if the haptic interface will lead to more effective learning, whether users accept a haptic interface to learn anatomy, and what factors affect learning and user acceptance. This paper focuses on evaluating user acceptance of the haptic interface.

2. METHODOLOGY

We used the design research approach, with iterations of system implementation, formative evaluation and cyclic enhancements to develop our haptic system (Bannan-Ritland, 2003; Collins et al., 2004; McKenney, 2001 and Reeves, 2006). To date, the system has been through two phases of development and user tests.

2.1 Interface and Interaction

The interface domain in this study comprises 3D modeling and 3D interface space with the Phantom Omni haptic device (Figure 1), which provides six degrees of freedom: three for position (x,y,z) and one each for pitch, yaw and roll (rotation in the forward vertical, horizontal and transverse planes). Force feedback gives different amounts of resistance to an input depending on the state of the virtual operation.



Figure 1. Haptic device (Phantom Omni) used in the system and user tests

The system supports functions such as moving selected organs, zooming, and rotating. Particular parts of an organ can be selected to display its name (Figure 2), and these labels can be turned on or off.

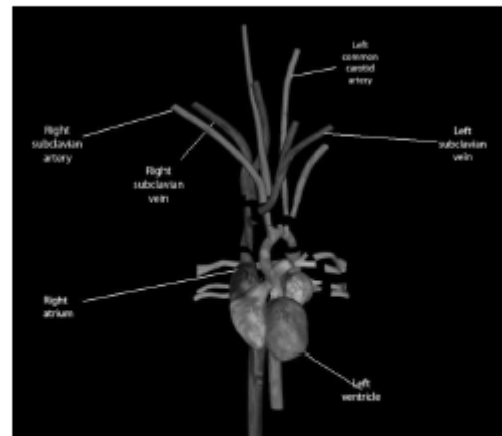


Figure 2. Screenshot of organs displayed in user test 2. Several labels have been turned on

The user receives tactile feedback, the force of which depends upon the part pressed. For example, different levels of surface deformation were set: the lung is 'spongy' (Figure 3), while the liver is firm. In Figure 3, the lung surface is being deformed, and the user is experiencing haptic feedback.

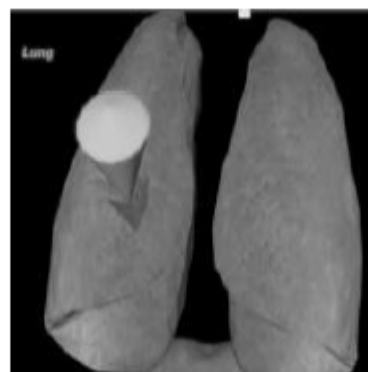


Figure 3. Screenshot of the lungs displayed with surface deformation in user test 1

The organs displayed in user test 1 included the lung, liver, and heart. For user test two, the organs displayed were the heart with its four chambers, and numerous blood vessels.

2.2 Development Environment

The computer system used in user test 1 was an Intel® Core™ Duo CPU @ 2GHz, RAM 2GB. An upgraded system was used in user test 2, which provided more sensitive feedback to the user. Its specification was Intel® Core™ i7-2600 CPU @ 3.4GHz, RAM 16GB.

2.3 Formative Evaluation

To investigate user acceptance of the haptic interface, we recruited first to third year undergraduate medical students and computing students at UTAS to try the system. For user test 1, an email invitation was sent to all (n=230) second and third year medical students. In addition, computing students engaged in activities in a computer lab were invited to test the system, which was set up in an office. For user test 2, all first year medical students (n=115) were invited to test the system during a practical laboratory class.

Demographic information and prior experience with computers and haptic devices was gathered from participants prior to each test via a short questionnaire. After a brief introduction to using the system, each user was free to explore it. The lead researcher and a research assistant observed the users, to observe how they learned to use the interface and any difficulties they encountered. After exploring the system, participants were asked to complete a questionnaire with both visual analogue scale (VAS) questions and an open response comment box on their experiences with the system.

Results of quantitative questions are presented as mean, standard deviation (SD), and standard error of the mean (SEM). T-tests were used to compare results from user tests 1 and 2, with significance level conservatively adjusted to $\alpha = 0.01$ using the Bonferroni correction for multiple comparisons (type I family-wise error rate of $\alpha = 0.05$ divided by 5, the number of comparisons). Quantitative analysis was performed in Excel and SPSS. Qualitative analysis of open response comments was through coding and identifying themes (Braun and Clarke, 2006).

3. RESULTS

3.1 User Test 1 Settings and Demographics of Participants

We emailed all year 2 and 3 Bachelor of Medicine, Bachelor of Surgery (MBBS) students at UTAS ($n=230$), inviting them to participate in our research project by trying the haptic system and completing a questionnaire. The system was set up in a vacant tutorial room at the School of Medicine campus, three times for two hours each, when at least some of the students did not have classes. In addition, some computing students at UTAS were invited to participate ($n=20$). The system was set up in an office at the School of Computing and Information Systems for two days.

In total, 18 students, 15 males and 3 females, tried the system and completed the questionnaire, including eight medical students (3.5% response rate) and ten computing students (50% response rate). The average age of all participants was 23, and four reported previous experience with haptic devices, but none with the Phantom Omni haptic device.

3.2 User Test 2 Setting and Demographics of Participants

Sample size calculations ($n = 2 * [(z_{\alpha} - z_{\beta}) \sigma / (\mu_1 - \mu_2)]^2$), based on an estimate of standard deviation (σ) of 22 derived from the average of the observed standard deviations on the five VAS questions relating to user acceptance in the first user test, and a desire to detect a difference in mean scores ($\mu_1 - \mu_2$) of 20 on the 100-point VAS with $\beta=0.20$ (power = 0.80, $z_{\beta}=-0.84$), yielded required sample sizes of $n=19$ at $\alpha=0.05$ ($z_{\alpha}=1.96$) and $n=29$ at $\alpha=0.01$ ($z_{\alpha}=2.575$). We emailed all year 1 MBBS students at UTAS ($n=115$), inviting them to participate in our research project by trying the system and completing a questionnaire. The system was set up at two practical laboratory sessions, each two hours long with half the class each. Twenty-seven students (23% response rate), 16 males and 11 females, tried the system, but only 25 participants completed the questionnaire, with two participants each not answering one question. More students wanted to try the system than were able to, and many students watched other students using the system. The average age of all participants was 19, and one reported previous experience with haptic devices, described as a mobile phone.

3.3 User Acceptance of the Haptic System

Participants were asked to complete a questionnaire immediately after using the system, which included VAS responses (scale of 0 to 100) and an open response comment box. The design of the questionnaire was based on the Technology Acceptance Model (TAM). According to the model, acceptability of a system is determined by two main factors, perceived usefulness and perceived ease of use (Chuttur, 2009). On average, participants rated the interface useful, easy to use, indicated that they performed well with the interface, and reported low levels of mental and physical stress (Table 1).

Table 1. Comparison of questionnaire responses in user tests 1 and 2

Question	User Test	n	Mean	SD	SEM	t	p
Did you perform well with the interface? (0=very poor to 100=very good)	1	18	71	19	4.5	1.02	.32
	2	24	63	22	4.5		
Was the interface useful? (0=totally useless to 100=very useful)	1	18	81	15	3.5	1.87	.07
	2	24	69	17	3.5		
Was it easy to use? (0=very difficult to 100=very easy)	1	18	73	18	4.2	2.13	.04
	2	25	58	20	4.0		
Did you become mentally stressed? (0=not at all to 100=very stressed)	1	18	22	30	7.1	-.44	.66
	2	25	32	27	5.4		
Did you become physically stressed? (0=not at all to 100=very stressed)	1	18	21	29	6.8	1.22	.23
	2	25	17	19	3.8		

Observing the participants using the haptic device during the first user test, we noted that when the cursor was moved too far in the z-axis, users found it hard to bring the cursor back. This was mitigated by the faster computer in the second test. The status of developed prototype was the main difference between two user tests. The user test 1 version included only three organs (heart, lungs, liver), and provided basic interaction with 3D models and haptic feedback. The user test 2 version had 28 objects (heart chambers and blood vessels), and increased functionality including clicking to make labels appear. There were some speed issues with version 2 when the users tried to do more complex activities such as moving smaller objects.

The questionnaire responses show that ease of use and perceived usefulness of the haptic interface decreased somewhat in the second test compared to the first, but these were not statistically significant at $p = 0.01$ (adjusted for multiple comparisons). In both user tests, most participants were using the haptic interface well after a few minutes. Questionnaire responses from the second user test indicated most participants would like to use the system as an aid to learning when fully developed, with an average value of 75 out of 100 ($n=21$ respondents to this question, $SD=17$, $SEM=3.8$; 0=not at all to 100=very likely). Responses to this question correlated positively with the questions on usefulness ($r^2=0.56$), ease of use ($r^2=0.31$), and performing well ($r^2=0.14$); however, there was no correlation with physical stress ($r^2<0.01$), and a weak negative correlation with mental stress ($r^2=0.07$).

Qualitative analysis of written comments on any aspect of the system involved coding the responses across both user tests, with 19 participants providing written comments. Seven participants requested additional functionality, relating to greater anatomical detail, more options to manipulate organs, or additional physiology or pathology content. Seven participants described system interface problems, relating to difficulty with placing the cursor, slow or jittery response, or the cursor getting stuck. In contrast, five participants praised the haptic feedback or other functionality, such as the ability to rotate organs. For example, one wrote: "I felt that the interface was appropriate for the task, with a high level of fine control permitted. I was impressed with the texture and density feedback test, there was a definite difference between the lung and liver in terms of feedback through the haptic interface." One participant wrote they didn't learn anything, another questioned usefulness for learning, and one described it as "fun". In contrast, two participants described the system as a useful learning tool, and two others wrote they would like to try it again when further developed.

4. DISCUSSION

Our main finding was that the majority of undergraduate computing and medical students who participated in this research study were favorable towards a haptic interface for exploring the structure and relationships of virtual 3D organs (Table 1). Our observations of the participants during the user tests suggest that students can rapidly learn to use the features of the system (moving organs, rotation, zooming, pressing organs). This was confirmed in questionnaire responses that most users found the system easy to use. This concurs with earlier work showing the 'naturalness' of the haptic interface, and the ease with which users adapt to it (Massie and Salisbury, 1994, Sankaranarayanan et al., 2003). The intuitiveness and ease of using a system like this should minimize extraneous cognitive load while learning from the system. However, open response feedback from the questionnaire indicates that further work is needed to smooth responsiveness of the cursor to movement of the haptic device; greater processor speed would assist. Many students would also like additional functionality to increase the potential to learn from the system. Most participants indicated they would like to use the system as an aid to learning when it is fully developed, suggesting intention to use this system. In agreement with the technology acceptance model (Chuttur, 2009), behavioural intention to use the system correlated strongly with perceived usefulness ('was the interface useful?', $r^2=0.56$) and perceived ease of use ('was it easy to use?', $r^2=0.31$).

The majority of participants in this study were young males. There were no obvious gender differences in accepting the new interface, with both males and females expressing enthusiasm. The smaller number of female volunteers may have been because fewer females were interested in trying a new technology system, or, in the second user test conducted during a regularly scheduled class (laboratory practical session), females may have been more focused on their learning tasks than males. We did not have a large enough number of participants to enable comparing responses by participant age. Anecdotally, one mature-age student showed frustration and stopped using the system. The current generation of 18-20 year old undergraduate students are 'digital natives' who have used technology since they were 5 or 6 years old (Prensky, 2001), confirmed in our questionnaire demographic data. In contrast, some older students may be less comfortable with new technology.

The greater interest (response rate) in the second test compared to the first may have been due to students seeing the haptic device, and watching others trying the device and expressing enthusiasm. In addition, the anatomical structures displayed (heart and blood vessels, Figure 2) were related to the learning objectives of the laboratory practical session (relating to introductory anatomy of several organ systems, including the cardiovascular system) at which the system was set up.

A limitation of this study is potential self-selection bias in the samples of students that tested the system. In the first user test, computing students and year 2 and 3 medical students were invited to try the system via email; there was a very low response rate (3.5%) from the medical students. In the second test, the system was set up in a laboratory practical class for first year medical students, and a higher, but still low response rate (23%) was obtained. In both cases, the students electing to participate in the research and try the system may have had a positive bias towards accepting new technology. Thus, the high level of user acceptance, and low self-reported levels of stress, may differ from the general undergraduate student population.

Although the user acceptance was not statistically significantly different between the first and second user tests, there were trends for decreased acceptance levels. Sample size calculations at power of 0.80 (80% chance of detecting an actual difference) yielded $n = 19$ or 29 at $\alpha=0.05$ or 0.01 , respectively. Our actual numbers of respondents to the questions were 18 and 24-25 in user tests 1 and 2, respectively, indicating we had somewhat less chance of detecting an actual difference between our two user tests. The trends towards decreased acceptance may have been due to different sample populations. In the first test, computing students and second and third year medical students were invited to participate. In the second test, we selected the group of students more likely to use the system in its present level of anatomical complexity, that is, first year medical students. It is possible that computing students, in particular, may have had a higher level of acceptance of the new technology.

5. CONCLUSION

We conclude that undergraduate medical students accepted a haptic interface to explore the structure and anatomical relationships of virtual 3D organs. However, the low response rate and positive self-selection may have resulted in a more positive response than the population. Additionally, positive responses may have been due to a novelty effect or that they were being observed trying the system. Further development of our system will provide another learning resource that engages multiple sensory systems for use by undergraduate medical students. However, a factor limiting wider availability of this system is the requirement for the computer peripheral, the haptic device. The next phase of the research is to develop learning activities including formative assessment opportunities, and testing materials to measure the users' learning achievement with the system compared to traditional learning resources.

ACKNOWLEDGEMENT

We thank the students that participated in the tests, and acknowledge the support of UTAS through a teaching development grant. This study was approved by the Human Research Ethics Committee at UTAS (ethics approval number H0011743).

REFERENCES

- Bannan-Ritland, B., 2003. The Role of Design in Research: The Integrative Learning Design Framework. *Educational Researcher*, Vol. 32, No. 1, pp. 21-24.
- Behringer, R. et al, 2007. Some Usability Issues of Augmented and Mixed Reality for e-Health Applications in the Medical Domain. *HCI and Usability for Medicine and Health Care Lecture Notes in Computer Science*, Vol. 4799, pp. 255-266.
- Braun, V. and Clarke, V., 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, Vol. 3, No. 2, pp. 77-101.
- Chien, C. et al, 2010. An Interactive Augmented Reality System for Learning Anatomy Structure. *International MultiConference of Engineers and Computer Scientists*. Hong Kong, pp. 370-375.
- Chuttur, M., 2009. Overview of the Technology Acceptance Model: Origins, Developments and Future Directions. *Sprouts: Working papers on Information Systems*, Vol. 9, No. 37 <http://sprouts.aisnet.org/9-37>
- Collins, A. et al, 2004. Design Research: Theoretical and Methodological Issues. *Journal of the Learning Sciences*, Vol. 13, No. 1, pp. 15-42.
- Dieperink, B., 2006. *The Effect of Retroactive Interference on Anatomical Learning Using a Virtual Learning Environment*. Thesis, University of Twente. <http://essay.utwente.nl/58744/>
- Dobson, J., 2009. Learning Style Preferences and Course Performance in an Undergraduate Physiology Class. *Advancement in Physiology Education*, Vol. 33, No. 4, pp. 308-314.
- Dunser, A. et al, 2008. A Survey of Evaluation Techniques Used in Augmented Reality Studies. HITlab, Christchurch, NZ.
- Liao, H. et al, 2010. 3-D Augmented Reality for MRI-Guided Surgery Using Integral Videography Autostereoscopic Image Overlay. *IEEE Transactions on Biomedical Engineering*, Vol. 57, No. 6, pp. 1476-1486.
- Massie, T. and Salisbury, J., 1994. The PHANTOM Haptic Interface: A Device for Probing Virtual Objects. *Proceedings of the American Society of Mechanical Engineers, Winter Annual Meeting. Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. <https://alliance.seas.upenn.edu/~medesign/wiki/uploads/Courses/Massie94-DSC-Phantom.pdf>
- McKenney, S., 2001. *Computer-based Support for Science Education Materials Developers in Africa: Exploring Potentials*. PhD Thesis, University of Twente.
- Murphy, R. et al, 2004. Student Learning Preferences and Teaching Implications. *Journal of Dental Education*, Vol. 68, No. 8, pp. 859-66.
- Nicholson, D. et al, 2006. Can Virtual Reality Improve Anatomy Education? A Randomised Controlled Study of a Computer Generated 3D Anatomical Ear Model. *Medical Education*, Vol. 40, No. 11, pp. 1081-1087.
- Prensky, M., 2001. Digital Native, Digital Immigrants Part 1. *On the Horizon*, Vol. 9, No. 5, pp. 1-6.

Appendix 4

ISBN: 978-972-8939-88-5 © 2013 IADIS

- Reeves, T., 2006. *Design Research from a Technology Perspective*. Routledge, London, England.
- Reiser, R., 2001. A History of Instructional Design and Technology: Part I: A History of Instructional Media. *Educational Technology Research & Development*, Vol. 49, No. 1, pp. 53-64.
- Sakellariou, S. et al, 2009. Design and Implementation of Augmented Reality Environment for Complex Anatomy Training: Inguinal Canal Case Study. In: Shumaker, R., (ed.) *Virtual and Mixed Reality*. Springer-Verlag, LNCS 5622, pp. 605-614.
- San Diego, J. et al, 2012. Researching Haptics in Higher Education: The Complexity of Developing Haptics Virtual Learning Systems and Evaluating Its Impact on Students' Learning. *Computers & Education*, Vol. 59, No. 1, pp. 156-166.
- Sankaranarayanan, G. et al, 2003. Role of Haptics in Teaching Structural Molecular Biology. *Proceedings of the 11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. <http://www.hitl.washington.edu/publications/r-2003-16/r-2003-16.pdf>
- Shams, L. and Seitz, A., 2008. Benefits of Multisensory Learning. *Trends in Cognitive Science*, Vol. 12, No. 11, pp. 411-417.
- Tan, S. et al, 2012. Role of a Computer-generated Three-dimensional Laryngeal Model in Anatomy Teaching for Advanced Learners. *Journal of Laryngology and Otology*, Vol. 126, No. 4, pp. 395-401.
- Temkin, B. et al, 2006. An Interactive Three-dimensional Virtual Body Structures System for Anatomical Training Over the Internet. *Clinical Anatomy*, Vol. 19, No. 3, pp. 267-74.
- Yeom, S., 2011. Augmented Reality for Learning Anatomy. *Proceedings of ASCILITE*. Hobart, Australia, pp. 1377-1383.
- Yushkevich, P. et al, 2006. User-guided 3D Active Contour Segmentation of Anatomical Structures: Significantly Improved Efficiency and Reliability. *NeuroImage*, Vol. 31, No. 3, pp. 1116-1128.

This article has been removed for
copyright or proprietary reasons.

Yeom, S., Choi-Lundberg, D. L., Fluck, A. E.,
Sale, A. (2017). Factors influencing
undergraduate students' acceptance of a
haptic interface for learning gross anatomy,
Interactive technology and smart education
14(1): 50-66. [http://dx.doi.org/10.1108/
ITSE-02-2016-0006](http://dx.doi.org/10.1108/ITSE-02-2016-0006)